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COVER. An adult *Hipposideros speoris*, a cave-dwelling, insectivorous bat. Young bats, carried by their mothers on the latters' foraging trips, probably acquaint themselves with the topography of their habitats and learn foraging strategies even before they can fly on their own. See page 602 for a study of infant-carrying behaviour of mother *Hipposideros* bats.

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In this issue

A weighty matter

The gyroscope, which is really a top when spinning fast, exhibits a most peculiar property of pointing to the same direction in space, irrespective of any movement of the base on which it is standing. It has therefore found important applications in terrestrial navigation and celestial navigation. This behaviour, although it appears mysterious, is explained on the basis of the principle of conservation of angular momentum, which is an extension of the classical law of the conservation of linear momentum. Classical physics does not allow the generation of a single force without a reaction. The weight of a gyroscope should therefore be independent of its rotational speed and whether or not it is spinning; nor should it vary whether the spin (angular rotation vector) is directed upwards (against the direction of the earth's gravitational field) or downwards. But this is exactly what the experiments of Hayasaka and Takeuchi of the Tohoku University found (*Phys. Rev. Lett.*, 1989, **63**, 2701). If true the result would overturn the foundations of classical physics. Indeed one could even dream of applying this strange effect to space travel.

The experiment that was performed was extremely simple: a plain gyroscope sitting on a pan of a laboratory balance with its rotor vertical was reported to exhibit an apparent loss of weight when its spin axis was pointing towards the centre of the earth and no loss of weight when the spin axis was pointing away. For a 175-g rotor at 13,000 rpm the loss of weight was about 10 mg, many times the claimed accuracy of the balance (0.3 mg). The loss was also proportional to the first power of the rotor mass and the angular velocity. All the possible precautions to eliminate interfering effects were taken (the enclosure was evacuated, the frame of reference inverted, magnetic screening, etc.).

There is no way in which the observation could be explained within the limits of classical mechanics. Spin–spin coupling between the rotating gyroscope and the earth of the type allowed by a variation of Einstein's theory of gravitation could be evoked; unfortunately the measured effects are too large. The theorist may go to town thinking even of effects due to neutrinos which are chirally asymmetric.

Publication of the results evoked criticism of the refereeing system and discussion on what a journal should do when the conclusions are so much contrary to current beliefs. What does the referee do when the data appear so good they will normally be accepted in less controversial fields? The editor of *Physical Review Letters* did (in our view) the right thing by just publishing the paper. Though this seems all right (for the authors, referees and editors), according to the editor of *Nature* (1990, **343**, 113), it is thoroughly unsatisfactory 'for the other interest group vividly engaged in the publication process—the readers'. We feel that while editors and referees must do everything to see that no papers with obvious errors are published in their journals they should not think that they are the final arbiters of what is ultimately correct in science. (Imagine stubborn editors/referees not publishing the result of the Michelson and Morley experiment as it contradicted conventional wisdom!). When in serious doubt all that editors can do is to expose the paper to the scientific public. This will immediately provoke new experiments which will confirm or contradict the unusual result by independent measurements.

This is what has happened in this case. Three groups, from India (C. S. Unnikrishnan, **page 600**), France and the US, repeated the experiment and obtained a null result: the mass of the spinning gyroscope is not dependent on speed or sense of rotation. For example, Unnikrishnan finds that there is practically no anomalous weight reduction. The effect is lower by a factor of 60 than that claimed earlier and any weight change which could depend on the magnitude of the spin is constrained to 2 parts in a million.

There have been speculations as to where error crept into the Japanese experiment (see *Nature*, 1990, **343**, 509).

A case of costs

We in India who also publish journals are watching from the sidelines the drama that is developing in the US and elsewhere in the 'business' of scientific publication. Scientific publishing involves big money. A reputed publishing company has sued three learned societies (**page 584**) for publishing a researched paper which indicates that the journals published by this company are among the most expensive in terms of ratio of cost to volume of scientific material published and ratio of cost to impact index (in terms of citation). Barschall, a reputed US physicist, carried out this interesting study; he too has been sued by the publishing house. We are told that any scientist who dares to write a letter to any journal complaining of the high cost of certain journals is apt to receive a communication saying that steps would be taken against him/her and also against the journal that publishes the letter 'to protect our clients' interests'. We are also told that this company has requested the Foundation of Scientific Cooperation in England to develop criteria for future surveys to assess the relative cost-effectiveness of scientific publications. There is some suspicion that funding for this impartial study may come from the same company, although this has been denied.

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CURRENT SCIENCE

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CORRESPONDENCE

Bamboo benefits

The editors deserve the congratulations of plant scientists for presenting the report of Nadgauda *et al.* in proper perspective and publishing the abstract of Rao and Rao presented at the International Bamboo Workshop held in 1988 (see *Curr. Sci.*, 1990, **59**, 346). Balaram has raised the question, 'Would we (as editors) have recognized the importance of the paper and highlighted it in our News column?' He also provides the answer 'probably not', implying that we (editors or plant scientists) fail to recognize significant findings. None in the plant science community recognized the importance of the earlier report of Rao and Rao.

Any new scientific development is of greatest interest to those likely to obtain maximum benefit from it. Who would benefit from *in vitro* flowering of bamboo? Obviously, plant breeders engaged in bamboo improvement programmes. But where are the bamboo breeding programmes in India, or, for that matter, anywhere else in the world? My survey of *Plant Breeding Abstracts*, published by the Commonwealth Agricultural Bureau (CAB International), for the last ten years under *Bambusa* and *Dendrocalamus* could not provide a single reference to breeding of bamboos. These abstracts cover a wide range of plant breeding journals. Flowering is not essential for the improvement of vegetatively propagated plants like bamboo, sugarcane, potato, cassava and grapes—some of the important crops that are propagated vegetatively, yet have been improved by selection.

We can also examine the possibilities for the improvement of bamboos assuming that routine flowering of all stocks can be obtained *in vitro* and hybrid seeds can be harvested (following the report of Nadgauda *et al.*) This provides two breeding options: (i) exploitation of heterosis (hybrid vigour) in the F_1 hybrids, as in maize and sorghum, and (ii) selection of superior individual plants in the F_2 and later generations, as practised in crops like wheat and rice. Both alternatives would need extensive field evaluation of the hybrids/selections. There are no alternative technologies to replace this long procedure. Normally, for annual crops it takes about 10–12 years for a new cultivar to reach the farmer after the appropriate crosses are made. The period can be reduced by growing two or at times three generations in a year. Further, positive selections are obtained only from a few crosses out of hundreds/thousands made each year. For bamboos it would take, at least, the full working life of a scientist (30–35 years). No private company would be interested in investing in long-term research. In the past, even publicly funded agencies have shied away from such projects in our country. It will also not attract any bright plant geneticist. Who is willing to wait that long?

Looking at it pragmatically, it appears that there has been an overreaction to an important scientific paper at all levels. *In vitro* flowering of bamboo, by itself, is an important and a small step towards breeding of better bamboos in future, and we should be proud of this development.

C. R. BHATIA

Bio-Medical Group
Bhabha Atomic Research Centre
Bombay 400 085

I am very much impressed by your treatment of 'bamboo flowers'. I enjoyed reading every bit of it and benefitted by getting to know a spectrum of views.

From my own long years of experience in industrial research and association with academia in India and abroad, I feel that our academic researchers are not well oriented towards ascertaining and protecting the potential commercial importance of their discoveries. On the other hand, practitioners of the purest sciences in the West are in constant touch with their industrial counterparts and, recognizing the value of their work, protect it before they publish. Of course, as Mascarenhas points out, NCL is quite patent-conscious. However, patenting and protecting a technique of the kind that he has published is very tricky and I hope that NCL has been properly advised.

K. NAGARAJAN

Searle (India) Limited
25 MIDC Land
Thane–Belapur Road
Thane 400 061

NEWS

Journal cost survey sparks row

A recent issue (May 14, 1990) of *The Scientist*, published by the Institute for Scientific Information, Philadelphia, reports that a temporary court injunction has been obtained by Gordon and Breach Science Publishers against the distribution in Germany of the November 1989 issue of the *Notices of the American Mathematical Society.* It is argued by Gordon and Breach that this issue carries an article that is prejudicial to their journals. The matter under dispute is the following.

Henry Barschall, a retired professor of physics in Wisconsin, USA, published in *Physics Today* (July 1988) an article based on a survey that analysed the subscription rates of physics journals published by various organizations. This analysis showed that the subscription rates of several journals published by Gordon and Breach were higher than those of journals published by others. Another survey published by the American Mathematical Society in November 1989 arrived at a similar conclusion.

Gordon and Breach, questioning the methodology adopted in the survey, sued the publishers of *Physics Today* (the American Institute of Physics), the American Physical Society and Barschall for publishing such comparative subscription surveys in the courts of France, Switzerland and West Germany, where the cases are still pending. It also sued the American Mathematical Society for the same reasons. As a consequence of this, the injunction has been given, withholding the distribution in West Germany of the November 1989 issue of *Notices.*

In the context of steep increase in journal prices and several budgetary constraints faced by libraries all over the world, surveys of this type, though not totally definitive, will certainly help libraries review their journal subscription lists. However, the methodology of the survey is a matter of opinion.

The controversy has evoked considerable interest among librarians, publishers, scientists and those who study such issues.

A. Ratnakar, Raman Research Institute, Bangalore.

RESEARCH NEWS

Fuzzy features promise to clear up quasicrystal structure

N. K. Mukhopadhyay

It is more than five years since the icosahedral phase was reported in rapidly solidified Al–Mn alloys by Shechtman *et al.*[1] This phase exhibits five-fold symmetry corresponding to the icosahedral point group in reciprocal space. In the diffraction patterns, unlike those of simple crystalline phases, the spots are not arranged periodically; however, the spots are reasonably sharp and their positions are related to one another by powers of $\tau\,(=(\sqrt{5}+1)/2$, the golden mean[2]). How can the diffraction patterns be explained? There are three main classes of models that have been proposed to understand such fascinating diffraction features. These are (i) crystalline models[3,4], (ii) icosahedral-glass models[5], and (iii) quasicrystalline models[6]. All these models can explain the diffraction symmetry of the icosahedral phase but not the intensities of the peaks. However, there are some subtle features in the diffraction patterns, purely from a geometrical point of view, that may be important in arriving at the correct model even without going into the details of intensity calculation. One such feature are the arcs of diffuse intensity reported for the first time by Mukhopadhyay *et al.*[7] in Al–Mn alloys; the arcs appear in special positions in the diffraction pattern and disappear after a suitable heat treatment, leaving weak and sharp ('superlattice') spots in those places[8]. The first report of arcs of diffuse intensity and superlattice reflections generated much excitement on both theoretical and experimental fronts. It is surprising that so far there have been no papers based on the twinning of crystallites or on classical crystallography to account for the diffuse intensity in icosahedral phases. The glass model, based on random packing of icosahedral clusters maintaining the orientational order, at present can predict only the position of the arcs but not the superlattice spots[9]. On the other hand, the quasicrystal concept seems to have got immediate support, and can be extended in a natural way to interpret reasonably well the phenomenon of diffuse intensity[10].

Quasicrystals have a periodic structure in higher dimensions. In the present case, for the icosahedral phase, it has been shown that the structure can be periodic in six-dimensional space. The 6D cubic lattices can be projected irrationally to generate the quasiperiodic structures. As in the case of 3D cubic lattices, there are three cubic Bravais lattices in 6D, namely simple cubic, body-centred cubic and face-centred cubic. These structures, after projection, can give rise to simple icosahedral (SI), body-centred icosahedral (BCI) and face-centred icosahedral (FCI) structures respectively. So far the diffraction patterns in rapidly solidified Al–Mn alloy can be successfully indexed by the SI model. But the centre of the arc of diffuse intensity cannot be assigned integer indices based on the SI model[7]. The superlattice spots arising from these arcs have been indexed following the BCI model by doubling the 6D lattice parameter of the SI model, as has been demonstrated by Mukhopadhyay *et al.*[8] This is the situation in reciprocal space.

Naturally, there is a real-space structure corresponding to the FCI geometry in 6D space whose reciprocal space is a BCI lattice. Clearly, there is an overall change in the diffraction patterns without disturbing the intense peaks. This indicates some sort of ordering reaction on the parent structure. Thus it has been proposed that partial ordering or short-range ordering leads to the arcs of diffuse intensity and perfect or long-range ordering gives rise to the superlattice spots, which changes the space group of the lattice in 6D space. From the quasicrystalline framework it is obvious that there is a realistic possibility of a disorder–order transformation in the icosahedral phase. However, the ordering in atomic scale is not yet known; first one must know where the atoms are in the quasicrystalline model. Work is in progress to resolve the issue with the help of 6D crystallography. Nevertheless, from geometrical considerations, the ordered structure in real space can be realized as an FCI-type superstructure of the SI lattice. One has to wait and see whether or not a BCI-type superstructure of SI is possible in any other alloy system. It is pertinent to point out that the diffraction patterns from Al–Fe–Cu and related alloy systems show evidence of FCI ordering of the SI structure in real space even without annealing[11, 12]. The long-range-ordered quasicrystals are highly stable and can be grown to a larger size suitable for single-crystal X-ray studies. These experiments are expected to yield more interesting data which will help to understand the structure of quasicrystals in the near future.

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N. K. Mukhopadhyay is in the Department of Metallurgy, Indian Institute of Science, Bangalore 560 012.

Electronic device screens chemicals for biological activity

Tara Ramaseshan

A new device invented at Stanford University, called a silicon microphysiometer, now allows routine measurement of the metabolic responses of cells to physical and chemical stimuli[1]. The principle that this device taps is that all biological, chemical or physical changes in the environment of a cell are reflected in changes in the concentration and flow of molecules within the cell. The extensive interconnection among the different biochemical processes allows the detection of a response that is only indirectly associated with the primary stimulus.

Catabolic processes are ideal candidates for the indirect detection of responses. The primary catabolic products in mammalian cells, carbon dioxide and lactic acid, cause changes in acidity in the environment of the cells, which therefore reflects the metabolic activity of the cells. The silicon microphysiometer, developed by Molecular Devices Corp., Menlo Park, California, uses light-addressable potentiometer sensors (LAPS) to measure changes in pH in the culture medium surrounding a small number of cells. It consists of a microvolume flow chamber in which the cells to be tested are immobilized. One wall of the chamber is the silicon-based LAPS. Apposed to the sensor, 100 μm away, is a coverslip with the adherent cells. Medium is pumped through the channel between the sensor and the coverslip. The medium, differing from normal growth medium in lacking bicarbonate, has reduced buffer capacity and thus enhances pH changes. For measurement of metabolic rate, flow of medium is halted for 30 to 200 seconds. Cells acidify the medium in the chamber because of production of lactate and some carbon dioxide. When flow is resumed the pH in the chamber rises and then returns to the pH of fresh medium. The rate of acidification of medium, measured by the microphysiometer, is a measure of the metabolic rate of the cells.

The immense potential of the device has been demonstrated in a recent study that evaluated the use of this instrument for continuous monitoring of receptor-mediated changes in the metabolic rates of living cells[2], demonstrating the instrument's utility in screening new therapeutic drugs by measuring cellular responses accompanying receptor–ligand interactions. The expected qualitative effects of various nonspecific toxic chemicals on the metabolic rates of cultured cells have also been seen in experiments that employed the microphysiometer.

The responses of the same receptors in different cell types and different receptors in the same cell type were studied. The β_2-adrenergic and m_1 muscarinic acetylcholine receptors, each representative of a major neuroreceptor class in the sympathetic and parasympathetic nervous systems, were investigated. Both are known to function through guanine nucleotide-binding proteins (G proteins). The responses were demonstrated in three different cell types, viz. human keratinocytes, Chinese hamster ovary (CHO) cells and murine fibroblasts, with receptors that use three different second-messenger systems.

These studies, which used the microphysiometer, showed that an increase in cellular metabolic rate is a general response of a cell to hormonal stimulation, and that responses are receptor-specific. Cells that express transfected receptor genes respond only to the appropriate hormone or transmitter. These studies also document specificity of responses using pharmacological antagonists[2].

Thus, among its many capabilities, the device can be used to:

(i) measure the metabolic response of tumour cells to chemotherapeutic agents, and thus be used to screen compounds for potential anticancer activity;
(ii) measure the responses of human cells to chemical irritants by *in vitro* toxicological assays, which can serve as a replacement for the controversial rabbit-eye Draize test of ocular irritancy;
(iii) trace the effect of virus infection on cells as well as the efficiency of antiviral agents at inhibiting the infection; and
(iv) measure direct responses of cells following ligand binding to receptor.

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Emerging dilemmas in the management of science and technology

Rajendra K. Bera

The impact of scientific discoveries and technological innovations has always been impossible to predict. It is more so in today's climate of fundamental shifts. Many of these shifts are related to science and technology. For example:

- Pursuit of science has become expensive. It needs government and hence political support for funds. Scientists are perforce turning into lobbyists.
- Modern society's dependence on science and technology is such that the competitive edge of industries today lies not just in new but increasingly in innovative technology whose basis is science. Naturally, industries have begun to play godfather to science and their funds carry considerable clout.
- Technology and, indeed, any form of application-oriented knowledge, has become an important marketable commodity. It has become an important component of international trade.
- Science is no longer pursued by gentlemen-of-leisure. It has become a profession. Scientists now rarely operate as individuals or in small groups. The functioning entity is now a large group requiring 'professional management', which means that it focuses on projects rather than on knowledge.
- The new keyword for survival in the marketplace is innovation. Frequently it means sloughing off yesterday's technology, yesterday's skills, and those of yesterday's work-forces that are unable to adapt with speed. As employment security becomes a thing of the past, how do we make people see this change as an opportunity and not as a threat? Unfortunately, innovative work cannot be organized and done within existing standard management components. It needs to be organized separately, with different structural principles, and in different structural components.
- Any technological innovation, when it comes to the marketplace, is a gamble. One cannot do market research for something genuinely new or for something that is not yet in the market. Its success depends on advertising, user preference, cultural biases, adaptation, perceived prestige, etc. It frequently requires a supporting cast. For example, TV has little meaning outside the context of TV programmes; cars outside the context of good roads, refineries and petrol stations; electric bulbs outside the context of power stations and power distribution networks; and so on. When such context-sensitive support requires large resources, governments necessarily step in. Innovation must then pay its obeisance to politics.
- New technologies are likely to involve big money, big consequences and big controversies. There will also be ethical concerns (such as those arising from genetic engineering) which may have a paralysing effect on technology development. For example, how do we bring new, beneficial, very expensive, but life-saving technologies to the aid of the poor? If some must be denied then what is the socially acceptable value system on which such denial is to be based? This is an area where basic science and technology must make 'common cause' with social sciences, humanism and religion.
- Recent technological strides have made people's expectations soar. They cannot be met without large-scale, impersonal automation in industry, home and services (specially, in information and diagnostic services).

Few, if any, would contest these observations. Indeed, a major shift in the technological foundations of the economy in several countries is already under way. It will surely present tremendous economic, social and political problems and produce many consequential dilemmas. Yet economists and social scientists barely acknowledge this fact, let alone account for it in their theories and comments. So it is highly unlikely that they will foretell the future.

On the other hand, since science is no longer a marginal activity in nation-building, scientists, to a large extent, will be expected to be accountable. Science is unlikely to be measurable even though its primary function is quantification. But science may, and should, be able to tell us what to expect, what to anticipate, and how to judge. This is important since, in the framing of government policies, science and technology are no longer afterthoughts; they are among its essential elements.

Science, however, has its limitations. It alone cannot solve all problems. Unless wisdom and sensitivity are brought to bear, scientific solutions may escalate into ominous political and social confrontations. In this light the growing nexus between politicians and scientists must be viewed with concern. There is already a tendency among certain scientists to bypass their scientific peers and go directly to people who have important political access. The scientific community must enforce strict self-discipline to curb such tendencies before the credibility of science as an institution is eroded beyond repair.

There is a keenly felt need for new ways of managing growth of science-based technologies. The new views must bear in mind at least the following: (i) the dramatic shift to knowledge-based industries requiring knowledge workers rather than blue-collar workers, (ii) the rapidity of the shift, and (iii) the consequent ecological changes.

Any new management perspective must recognize that societies function around organizations and institutions, and that technologies must nurture the country's developmental priorities. Therefore, technological innovations must match steps with social innovations. Technologies can be imported for a price but the institutions that must support them need cultural roots to grow and prosper. This is what makes technology transfer to an alien society so unreliable.

A few technology-generated social changes are already in evidence. For example, social groups are increasingly being identified not by their socio-economic status but by their lifestyles; professionals are looking less for employment security and more for employability security; national power and pride is no longer measured in military terms but in shares of world markets and in technological prowess.

An important aspect of technology is to do something better; its most important aspect is to do something new. Thus innovation is the key — the search for and the exploitation of new opportunities for satisfying human wants and human needs. Rapid spread of technology will affect social values, perceptions, attitudes and demographics (migration, education levels, sources of employment, etc.). Already, in affluent societies, populations have become unstable and are subject to sudden sharp changes in location and lifestyle. Today the world must also contend with an ageing population in the developed countries alongside a tidal wave of young adults in the Third World. With dramatic increases in international co-operation, travel and trade, the impact will be global and confusing. The tragedy of modern technology is that, while it produces material prosperity, it also uproots people from their cultures, their families and their tribes, and creates in them disabling emotional vacuums.

Science has won for itself certain social concessions — freedom from politics, religion, hierarchy, even national boundaries. In technology-dominated systems these freedoms percolate and traditional hierarchical management is unable to resist the percolation. Thus, in a growing number of institutions, horizontal ties between peers are replacing vertical ties as channels of activity and communication. Superiors and subordinates as concepts are in many instances being shoved aside. Career paths are no longer straightforward or predictable but idiosyncratic and confusing. Authority and power associated with a hierarchical position can no longer be taken for granted since the key to competitive success is now centred on the knowledge workers. This creates problems of how to mobilize and motivate staff since everything now seems negotiable by everyone.

Today managers find that they have no book to follow, that they cannot take a hierarchy-based flow of power and authority for granted, that they have only themselves to count on for success, that subordinates are encouraged to think for themselves, that success depends increasingly, indeed crucially, on tapping into sources of good ideas and good collaborators. There is no past history for guidance. Industries are becoming leaner and flatter. Knowledge indeed now translates to raw power. Defection of one or a few key knowledge workers can bring ruin to a company or spawn a powerful competitor. Business must continuously innovate to stay competitive.

Any kind of progress requires gradients. Generally, the more rapid the progress, steeper the gradient. Thus preconditions of social and economic progress are disparities in salaries, status, recognition, etc. Progress generates its own dynamics. For progress to be sustainable it must assure that gradients do not become too steep, so that there is enough time for the fruits of progress to percolate down to a reasonable degree. However, too rapid or too uniform a percolation would even out the gradients and progress would come to a standstill. To people sameness appals and boredom, like tyranny, is the precursor to social unrest.

Rapid growth is bound to create islands of prosperity. This can create problems of conscience, which can easily lead to misplaced altruistic concepts of a welfare state. Since the price of such concepts is payable in the future, the present will be tempted to adopt a cavalier attitude. Welfare is best met by adequate surplus productivity. Otherwise one may easily walk into the trap of an uncontrolled, and perhaps uncontrollable, inflationary deficit.

Rapid changes make their management impossible because there is no time for ethical reflections, to collect data, and to evaluate their impact. On sociological time-scales, rapid changes are not even quasistationary and there is no past experience for guidance except that they generally produce chaos and collapse. A good deal of management practices in the past has evolved through time-tested wisdom embedded within a culture. That wisdom holds even today but people are in too much of a hurry to exercise it. Adapting oneself to the hectic present has already become an exhausting task, so the future is often blindly mortgaged. Today's economists and social scientists do not even understand the nature of the technological forces at work or the mental make-up of the knowledge worker. So they cannot provide timely warnings and advice on what to avoid or what to pursue.

Control of inadvertent ecological damages created by technological growth will require massive data collection and analysis, in itself a major financial burden. It furthermore requires a global watch system dependent upon co-operation among nations. Mankind may yet be decimated, not because of World War III but because of technological growth careering out of control. Even though predicting the impact of technology is inherently impossible, its monitoring is not. Technology monitoring, often enough, allows us to gain experience in the complex way it interacts with society and the environment and hence of its likely future impact in the short term. This, in turn, permits, in many instances, containment of its adverse effects, or at least provides an early warning of such effects.

Conventional means of estimating gross national product and other standard measures of progress have already become inadequate. They merely look at increases in output and neglect to account for the irreplaceable loss of natural resources, pollution costs, and other environmental damages (depletion of the ozone layer, contamination of rivers, oceans and subsoil water, smog, acid rain, the greenhouse effect, etc.) they cause. It is estimated that paper, glass, metal and plastic packaging constitute 50% of US garbage by volume and 30% by weight, a frightful indicator of where the Third World might be heading as it industrializes. Immediate global steps are needed to preserve rain forests, freshwater sources, topsoil and a clean atmosphere. Technology must develop recyclable products, specially in packaging. The motto should be 'waste not, want not' and 'recycle, reuse, repair'. While nature may be resilient enough to survive the ecocatastrophies that we burden it with, it might well do so by first wiping out the human race!

The future, however, need not go completely out of hand, or the human race into oblivion, if considered political actions are initiated right away. Presently there is no political mechanism to slough off the old, the outworn, the no longer productive, specially in government. We need some 'sunset laws', not just 'sunrise laws', an organized process of abandonment and replacement of laws and institutions that have become dysfunctional. We need to encourage habits of flexibility, of continuous learning, and of acceptance of change as normal, indeed as opportunities. And what better incentives than tax laws which encourage moving capital from yesterday into tomorrow.

Rajendra K. Bera is in the Computational and Theoretical Fluid Dynamics Division, National Aeronautical Laboratory, Bangalore 560 017.

Diophantine equations

V. Srinivas

This article gives an introduction, accessible to non-specialists, to the topic of Diophantine equations. Mainly, this is the study of solutions of polynomial equations $f(x_1,\ldots,x_n)=0$ in whole numbers (integers), where the polynomial f has integer coefficients. This is broadened to include the study of solutions of one or more such equations in rational numbers (fractions) and algebraic numbers. A famous example of a Diophantine problem is given by Fermat's Last Theorem, which is the statement that $x^n+y^n=z^n$ has no solutions where x, y, z are positive whole numbers (natural numbers), if n is at least 3. This problem is still unsolved. Another well-known equation is $x^2-Ny^2=1$, where N is at least 2; this equation was studied by Indian mathematicians like Brahmagupta and Bhaskara. The article gives some historical background, including the works of Fermat, Gauss and others, leading up to a discussion of some current development — the work of Faltings, and new ideas related to Fermat's Last Theorem.

Diophantine equations are polynomial equations with integer coefficients, for which we wish to find integer solutions.

For example, consider the equations

$$x^2=2y^2, \tag{1}$$
$$x^2=2y^2+1. \tag{2}$$

The first equation has only one integer solution, $x=y=0$, since $\sqrt{2}$ is irrational. However, the second has infinitely many integer solutions (one verifies, with a bit of algebra, that if we write $(1+\sqrt{2})^{2n}$ in the form $a_n+\sqrt{2}b_n$ for some integers a_n, b_n, then $x=a_n$, $y=b_n$ is a solution of equation (2); for example, if $n=1$, we have $(1+\sqrt{2})^2=3+2\sqrt{2}$, and $x=3$, $y=2$ is a solution of equation (2)).

Certain problems, stated in geometrical language, reduce to Diophantine equations. For example, consider the problem of finding right angled triangles in the plane whose sides have integral length; from Pythagoras' theorem, this reduces to finding positive integer solutions of the equation

$$x^2+y^2=z^2$$

This problem has infinitely many solutions; one may verify that for any positive integers a, b with $a>b$, we have a solution

$$x=a^2-b^2,\ y=2ab,\ z=a^2+b^2;$$

this is equivalent to the algebraic identity

$$(a^2-b^2)^2+4a^2b^2=(a^2+b^2)^2.$$

From our first pair of examples, one sees that in order to understand integer solutions of Diophantine equations, there is sometimes an advantage in considering related problems over larger number systems, which contain the integers. In our examples, one considers the number system consisting of all numbers of the form $a+b\sqrt{2}$, where a, b are integers. Such a number system will form a *ring*, i.e. it will be closed under addition and multiplication; it is called a ring of algebraic numbers.

Next, if we seek integer solutions to $x^2+y^2=z^2$ with the additional condition $z\neq 0$ (which is not a severe restriction, since $x=y=z=0$ is the only solution with $z=0$), then a solution

$$x=a,\ y=b,\ z=c$$

yields a solution in *rational numbers* (fractions) of the equation

$$X^2+Y^2=1,$$

given by $X=a/c$, $Y=b/c$. Conversely, if we have a solution $X=A$, $Y=B$ of $X^2+Y^2=1$, where A, B are rational numbers, then we can write A, B as fractions with a common denominator, say

$$A=a/c,\ B=b/c;$$

then $x=a$, $y=b$, $z=c$ is an integer solution of $x^2+y^2=z^2$.

The term *Diophantine equation*[1] originates from the work of Diophantus of Alexandria, who first studied integer and rational solutions of equations. One of Diophantus' main results is about linear equations—if a, b, c are given integers, then the equation

$$ax+by=c$$

either has no integer solutions (x, y), or it has infinitely many; there are infinitely many solutions precisely when the *greatest common divisor* (g.c.d.) of a and b divides c. Thus,

$$25x+15y=127$$

has no integer solutions, since the g.c.d. of 25 and 15 is 5, which does not divide 127, while

$$25x+15y=125$$

has infinitely many solutions (5 divides 125). Diophantus

V. Srinivas is in the School of Mathematics, Tata Institute of Fundamental Research, Bombay 400 005.

also discusses certain quadratic equations (e.g. $x^2+y^2=z^2$).

Ancient Indian mathematicians were also interested in integer solutions of problems[2]. The solution of linear equations mentioned above was known to Aryabhatta (5th–6th century AD). The equation $x^2-ny^2=1$, for any positive n, was studied by Brahmagupta (7th century), and the general solution was found independently by Jayadeva (11th century) and Bhaskara (12th century).

Probably the most famous (infamous?) Diophantine equation is 'Fermat's Last Theorem'[3]. The chapter on Fermat in E. T. Bell's *Men of Mathematics*[4] is titled 'The Prince of Amateurs'. This refers to the fact that Fermat is the most famous example of a mathematician who was not a 'professional', i.e. a professor at a university, or supported by a wealthy patron. Pierre Fermat (1601–1665) was a commissioner of requests, and later a King's councilor in the *parlement* (the provincial High Court of Judicature) at Toulouse, in France. He seems to have become interested in mathematics in his late twenties, perhaps through the influence of d'Espagnet, also a magistrate, who was mathematically inclined. Fermat published none of his results, but communicated them to some friends, notably Father Mersenne, in personal letters. Nevertheless, when he died, he was one of the most famous mathematicians in Europe. Today he is best remembered for his work on number theory, particularly Diophantine equations; yet, in his day, he was better known for his work on geometry, calculus, probability, and optics. In his book[5] *Number theory—An approach through history*, Andre Weil writes of Fermat, '... it is clear that he always experienced unusual difficulties about writing up his proofs for publication; this awkwardness verged on paralysis when number theory was concerned, since there were no models there, ancient or modern, for him to follow.' Quite clearly, if Fermat were alive today, he would still have to remain an amateur! Weil also writes (of the notoriety of 'Fermat's Last Theorem') that 'his (Fermat's) reputation in the eyes of the ignorant came to rest chiefly upon it'.

'Fermat's Last Theorem' is the statement that for any integer $n\geqslant 3$, the equation

$$x^n+y^n=z^n$$

has no *positive* integer solutions (x, y, z) (equivalently, if (x, y, z) is an integer solution, at least one of x, y, z is zero). Fermat did not announce this result. However, after Fermat's death in 1665, his personal annotated copy of Bachet's *Diophantus* was examined by his son Samuel, while preparing an edition of his father's works. In the margin alongside Diophantus' discussion of $x^2+y^2=z^2$, Fermat remarks, 'No cube can be split into two cubes, nor any biquadrate into two biquadrates, nor generally any power beyond the second into two of the same kind'. He adds that he has discovered a 'truly remarkable proof' for this fact, which 'this margin is too narrow to hold'. Since this notation was found, many mathematicians have struggled (without success) to prove (or disprove) Fermat's assertion. A lot of partial progress has been made, including some recent progress (which we describe later). There were controversies and priority disputes between prominent mathematicians over claimed proofs, which eventually turned out to be incorrect; a prize of 100,000 Marks was offered by Prof. Paul Wolfskehl, a German mathematician, for the first correct solution. This prize amount was greatly devalued after the First World War, but in the foreward to his book[6] on Fermat's Last Theorem, H. E. Edwards wrote (in 1977) that the prize still existed, and was then worth DM 10,000. Claimants for the prize should submit their proofs for scrutiny to the Academy of Sciences in Göttingen.

New light on the subject of prizes (and perhaps on Hilbert!) is shed by the following anecdote[7] about the mathematician David Hilbert, of Göttingen. Hilbert was the chairman of the prize committee that decided on the correctness of proofs of Fermat's Last Theorem; as long as the prize money remained unclaimed, the interest on it was available to the Göttingen mathematics department to invite prominent academic visitors to Göttingen. Hilbert is reputed to have said, 'It's lucky that I am probably the only person who can crack that nut. But I shall take very great care not to kill the goose that lays us such splendid golden eggs'.

Fermat himself described a proof that the special case $x^4+y^4=z^4$ has no positive integer solution, by a new technique, now called Fermat's method of *infinite descent*. In fact, Fermat proved the more general statement[8] that

$$x^4+y^4=w^2$$

has no 'non-trivial' (i.e. with $w\neq 0$) solutions. If $x=a$, $y=b$, $w=c$ is a nontrivial solution, let

$$h=\text{maximum of } a, b, c;$$

call h the *height* of the solution. Then h is a positive integer. However, Fermat was able to show that, given one non-trivial solution $(a, b. c)$ with height h, one must have another non-trivial solution (a', b', c'), with height h', such that $h'<h$. Repeating Fermat's argument, one would obtain an infinite sequence (a_n, b_n, c_n), $n=1, 2, 3, \ldots$ of solutions, with heights $h_1=h$, $h_2=h'$, $h_3, \ldots$ which form an *infinite, strictly decreasing sequence of positive integers*. This is clearly a contradiction; such a sequence does not exist.

Let $\zeta_n=\exp(2\pi i/n)$, which is an nth root of unity (i.e. the nth power of ζ_n equals 1). One can consider the number system consisting of all complex numbers of the form

$$a_0+a_1\zeta_n+a_2\zeta_n^2+\ldots+a_{n-1}\zeta_n^{n-1},$$

where the a_j are all integers. This system forms a ring (i.e. is closed under addition and multiplication), as one can see by using the equation $\zeta_n^n = 1$. It is a familiar fact, first proved by Euclid, that any natural number can be factorized into prime factors, and the factorization is essentially unique. If one assumes an analogous statement for the number system obtained from ζ_n, it is possible to prove by 'infinite descent' that Fermat's Last Theorem is true. Some mathematicians believe that this might be the argument that Fermat had in mind; however, the German mathematician Kummer found that unique factorization is *false* for the number system formed from $\zeta_{23} = \exp(2\pi i/23)$ (and this turns out to be the case for infinitely many ζ_n).

Certain mathematicians, the most prominent of whom was Carl Friedrich Gauss, were less interested in solving specific equations, like the one in Fermat's Last Theorem. They preferred to try to understand why some equations could be solved, and not others, and why there were sometimes only a finite number of solutions, and why there were infinitely many solutions in other cases. In other words, they wished to develop a *theory*[9] of Diophantine equations. Gauss himself, based on his famous quadratic reciprocity law, achieved a thorough understanding of *quadratic* diophantine equations in 2 variables

$$f(x, y) = 0.$$

For example, consider the equation

$$x^2 + xy + 5y^2 = p,$$

where p is a given prime number. Gauss' methods show that this equation has an integer solution (x, y) (which is essentially unique) precisely when $p = 19$ (when $x = -1$, $y = 2$ is a solution), or else, on dividing p by 19, one obtains one of the following remainders:

$$1,4,5,6,7,9,11,16,17,$$

(these are the possible non-zero remainders obtained by dividing *squares* of integers by 19). For example, it is known that $p = 2^{127} - 1$ is a prime number[10]. One computes that p leaves a remainder of 1 on division by 19 (since $2^9 = 512$ leaves a remainder of 18, i.e. of '-1', $2^{18} - 1$ is divisible by 19; but

$$(2^{127} - 1) - 1 = 2^{127} - 2 = 2\,(2^{126} - 1) = 2\,((2^{18})^7 - 1)$$

which is divisible by $2^{18} - 1$, and hence by 19. Hence

$$x^2 + xy + 5y^2 = 2^{127} - 1$$

has an integer solution. The special role played by 19 is because the *discriminant* of the quadratic expression is -19 (the discriminant of $ax^2 + bxy + cy^2$ is $b^2 - 4ac$). A more spectacular example is the statement that

$$x^2 + 5xy + 47y^2 = 2^{11213} - 1$$

has an integer solution[11]. Gauss also studied generalizations of quadratic reciprocity, which eventually led Hilbert and others to what is now called *class field theory*[12].

The first general result on higher degree equations was obtained by the Norwegian mathematician Axel Thue, in 1910. Let $f(x, y)$ be a homogeneous polynomial of degree $d \geqslant 3$, i.e. we can write

$$f(x, y) = \sum_{r=0}^{d} a_r x^r y^{d-r},$$

where the a_r are all integers; assume $a_d \neq 0$. Suppose f cannot be factorized as a product of two polynomials of smaller degree, with integer coefficients. Then for any integer $m \neq 0$, Thue showed that the equation

$$f(x, y) = m$$

has only a *finite number* of integer solutions. The proof is based on the following idea: write

$$f(x, y) = a_d \prod_{r=1}^{d} (x - \alpha_r y).$$

where $\alpha_1, \alpha_2, \ldots, \alpha_d$ are the (complex) roots of the equation

$$f(t, 1) = a_0 + a_1 t + a_2 t^2 + \ldots a_d t^d = 0.$$

If $x = p$, $y = q$ is an integer solution of $f(x, y) = m$, then

$$a_d \prod_{r=1}^{d} (p - \alpha_r q) = m,$$

so that on division by q^d we get

$$\prod_{r=1} \left(\frac{p}{q} - \alpha_r\right) = \frac{m}{a_d q^u}$$

If q is very large, then since $m/(a_d q^d)$ is very small, p/q must be a very good approximation to one of the roots α_r. On the other hand, Thue managed to show that such a good approximation cannot exist[13]. Thus, the integer solutions of $f(x, y) = m$ have a bounded value of y; this easily shows that the corresponding x values are also bounded, and hence there are only a finite number of solutions. Carl Ludwig Siegel refined Thue's ideas to find necessary and sufficient conditions for an arbitrary Diophantine equation (in 2 variables, with integer coefficients)

$$f(x, y) = 0$$

to have infinitely many integer solutions. These conditions are best understood in terms of the geometry of the *algebraic curve* given by the solutions of the above equation over **C**, the complex numbers.

If $f(x, y)$ has degree d, we can uniquely decompose f as

$$f(x, y) = h(x, y) + k(x, y)$$

where h is the sum of the terms in f of degree exactly d (i.e. the terms involving $x^i y^{d-i}$ for $0 \leqslant i \leqslant d$), and k the sum of the terms of f of degree $\leqslant d-1$. Since h is homogeneous of degree d we may factorize it (as seen earlier during the discussion of Thue's work)

$$h(x, y)=a \prod_{i=1}^{d} (x-\alpha_i y)$$

for certain complex numbers $\alpha_1 \cdot \alpha_2, \ldots, \alpha_d$, and a non-zero integer a (this assumes that h has a non-zero coefficient of x^d, but this can be arranged after a homogeneous linear change of variables). Some of the α_i may be repeated; suppose there are exactly s distinct α_i. It turns out that if we let U be the subset of the complex 2-dimensional space $\mathbf{C}^2$ consisting of the complex solutions to the equation $f(x, y)=0$, then one can 'adjoin' s points to U, to get a space X which is a 'compact Riemann surface with singularities'. Intuitively, we may argue that $\mathbf{C}^2$ is 4-dimensional, while the equation $f(x, y)=0$ with complex coefficients really defines 2 equations with real coefficients; now the space of solutions of a system of 2 equations in a 4-dimensional space ought to be 2-dimensional, in general.

One can prove that, in fact, such a space X has the following description. Punch an even number of circular holes (say, $2g$) in the surface of a (two-dimensional) sphere; then attach g (hollow) cylinders to the punctured sphere, so that each boundary circle of each cylinder exactly matches the boundary of one of the holes; further, the cylinders do not intersect each other, or the sphere (except along the bounding circles). One obtains a surface without a boundary, which looks like a sphere with g hollow cylindrical 'handles', also called a *g-holed torus*. The number of handles is called the *genus* of the surface. Finally, to obtain our space X, one may have to pinch this surface in a finite number of places; these are the 'singularities' of X.

There are theorems which allow one to compute the genus g of X by simple algebraic procedures starting with the polynomial $f(x, y)$; for a 'general' polynomial f of degree d (i.e. when the space X has no singularities), one has the formula

$$g=(d-1)(d-2)/2.$$

In general, one subtracts a positive correction term which is a measure of the singularities[14].

Siegel's result states that if $g>0$, then the Diophantine equation $f(x, y)=0$ has only a finite number of integer solutions; further, even if $g=0$, only certain very special equations can have infinitely many solutions.

The problem of finding all *rational* solutions to Diophantine equations $f(x, y)=0$ is harder. It turns out that equations[15] of genus 0 and 1 may have infinitely many rational solutions. For equations of genus 0, one can decide if this is the case by simple calculations involving f, and Gauss' quadratic reciprocity law. However, it is a very difficult problem, and the subject of much contemporary research on Diophantine equations, to prove such a criterion for equations of genus 1. One knows that the solutions to an equation of genus 1 form a *group* (after we add on a finite number of 'solutions at infinity'). An important result due to Mordell is that this group is *finitely generated.*

For equations of genus $\geqslant 2$, the *Mordell Conjecture* asserts that there are only a *finite number of rational solutions.* Thus, for the Fermat equation

$$x^n+y^n=1,$$

it turns out that there are no singularities, so that the genus is

$$(n-1)(n-2)/2,$$

which is $\geqslant 2$ if $n \geqslant 4$. Thus the Mordell Conjecture implies that, for each $n \geqslant 4$, the Fermat equation has only a finite number of rational solutions.

The Mordell Conjecture was proved by the German mathematician Gerd Faltings[16] (now at Princeton University), in 1983; he was awarded the Fields Prize for this work in 1986, at the International Congress of Mathematicians held at Berkeley, California, in the USA. As the reader may know, there is no Nobel Prize in mathematics; however, there is the Fields Prize, awarded every four years to two to four mathematicians at the International Congress. One difference with the Nobel Prize is that there is an age limit: only mathematicians below forty can qualify! The Fields Prize is not nearly as large a sum of money as a Nobel Prize, but of course it carries enormous prestige in the mathematical community. Incidentally, the Swedish Academy has recently instituted a prize in mathematics, the Crafoord Prize; the first persons to whom this was awarded (in 1988) were Alexandre Grothendieck and Pierre Deligne (both Fields Prize winners). However Grothendieck turned it down![17]

Faltings' proof is quite difficult, using advanced techniques from algebraic geometry and number theory developed by many mathematicians (following ideas of Grothendieck). However, one key step in the proof is an argument reminiscent of Fermat's method of infinite descent, again involving the notion of *heights.* Fermat's Last Theorem has been verified for all values of n up to 100,000; however, Faltings' result gives the best known result valid for *all n.* Of course, Fermat's Last Theorem concerns only one equation for each degree n, while Faltings' result applies to virtually *all* equations of degree $\geqslant 4$.

Finally, we describe two recent developments relating to Fermat's Last Theorem. The first one is regarded by some number theorists as the first 'real' evidence in favour of the truth of Fermat's assertion. There is a vast program of research (it is too wide in scope to be called a mere conjecture!) proposed by the Canadian born mathematician Robert Langlands (now at the Institute for Advanced Study in Princeton). Very roughly, this seeks to tie together the representation theory of Galois groups of fields of algebraic numbers (like the field of rationals), and Fourier analysis on so called *adele groups*, built out of real Lie groups and *p-adic groups* (like $GL_n(\mathbf{Q}_p)$, the group of $n \times n$-invertible matrices of *p-adic numbers*[18]) for all primes p. Fourier analysis on such groups is an active area of current research, which is built on the tremendous work[19] of Harish-Chandra, arguably the greatest Indian mathematician after Srinivasa Ramanujan.

Class field theory (the generalization of Gauss' quadratic reciprocity found by Hilbert and others, mentioned earlier), which includes a sizeable chunk of all results in algebraic number theory until a few decades ago, is reinterpreted as the simplest case of the Langlands program. This theory also generalizes the theory of certain functions called *modular forms*, which many number theorists have been interested in during the last 100 years or so. For example, Ramanujan was interested in the function (which is a modular form)

$$\Delta(z) = q \prod_{n=1} (1-q^n)^{24} \text{ (where } q = \exp(2\pi i z));$$

one of his most famous conjectures[20] about the Fourier coefficients $\tau(n)$ of the function $\Delta(z)$ (which was proved by Deligne in 1973) has been vastly generalized by Langlands. There is a lot of recent research giving impressive evidence in support of the Langlands program[21].

One consequence of the theory is a certain property of equations of genus 1 with rational coefficients, which goes under the name of the *Taniyama–Weil Conjecture* (after the mathematicians Taniyama and Weil). Recently, it has been observed by several mathematicians that this conjecture implies Fermat's Last Theorem. The idea is as follows—if a, b, c are integers satisfying $a^n + b^n = c^n$, one considers the cubic equation

$$y^2 = (x-a^n)(x-b^n)(x-c^n).$$

Then one is able to show that this cubic has genus 1, and would contradict the Taniyama–Weil Conjecture. Since Taniyama and Weil are backed up by Langlands, it seems unimaginable (to some) that Fermat's Last Theorem could be false! The auxilliary cubic obtained from a possible counterexample to the Fermat problem is called the Frey curve, after the mathematician Frey who first had the idea of studying this curve.

A variant of this method, again by considering the Frey curve, is to try to obtain a contradiction using another new topic in geometrical number theory, called *Arakelov theory*. This theory originates in a paper of the Soviet mathematician Arakelov[22]. Roughly speaking, Arakelov exploits an analogy between the geometry of surfaces and the theory of solutions of Diophantine equations $f(x, y) = 0$. A forerunner was the work of Weil[23], formulating such an analogy between the theory of algebraic curves, and the study of solutions of equations $f(x) = 0$ in one variable, i.e. of the rings of algebraic numbers we mentioned earlier.

There was much excitement in the mathematical community when in 1988, a Japanese mathematician announced that he could extend to the 'Arakelov situation' a geometrical theorem about algebraic surfaces which he had proved a few years earlier, and that this yields Fermat's Last Theorem. Unfortunately the proof was incorrect. However, these methods could still potentially lead to a proof.

Rational solutions of equations in 2 variables are related to integer solutions of equations in 3 variables (as in Fermat's Last Theorem). What about integer solutions of equations in $\geqslant 4$ variables? In his famous address to the International Congress of Mathematicians in 1900 in Paris, Hilbert listed 23 outstanding problems in different branches of mathematics, as a challenge to future mathematicians[24]. *Hilbert's 10th problem* asks for an algorithm (or systematic 'mechanical' procedure) for deciding if a given Diophantine equation has a positive integer solution. Using methods of mathematical logic (related to Gödel's famous *incompleteness theorems*, and to certain techniques in modern theoretical computer science), the Soviet mathematician Matijasevic, building on work of Martin Davis, Julia Robinson and Hilary Putnam, showed that there is *no such procedure*[25]. Refinements of the proof show that such a decision procedure is impossible for equations in 4 variables! Among the other striking consequences of this work, Matijasevič constructs an explicit polynomial f in 26 variables (named $a, b, \ldots, z$, of course!) such that for *any* positive integer solution of

$$f(a, b, \ldots, z) = 0,$$

a is a *prime number*, and *every prime number occurs in this way*!

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5. Weil, A., *loc. cit.*
6. Edwards, H. E., *loc. cit.*
7. Jungk, R., *Brighter than a Thousand Suns*, Penguin Books Ltd. 1964.
8. Use the substitution $w = z^2$.
9. Weil (*loc. cit.*) states that the majority of Fermat's work on Diophantine equations was concerned with the systematic study of equations of genus 0 and 1 (see Notes 14, 15 for genus). Thus Fermat initiated the 'theory' of these equations.
10. See Hardy, G. H. and Wright, E. M., *loc. cit.*, Section 15.5.

11. It is known that 2^{11213}—1 is a prime; granting this, the verification of this statement using quadratic reciprocity took the author less than 10 minutes of computation, without a calculator; essentially, one must compute the remainder obtained on dividing 2^{11213}—1 by 163, the discriminant in this case.
12. For the algebraic number theory needed to perform the above calculations, see any one of the following books:
Borevich, Z. I. and Shafarevich, I. R., *Number Theory, Pure and Applied Mathematics*, Vol. 20, Academic Press, New York, 1966; Marcus, J. A., *Number Fields*, Universitext, Springer-Verlag, New York, 1977; Serre, J. -P., *A Course in Arithmetic*, Grad. Texts in Math., No. 7, Springer-Verlag, New York, 1978 (also available in International Student Edition, Narosa, New Delhi, 1979); Marcus' book also contains an introduction to class field theory.
13. Thue showed that if α is a root of $f(t, 1) = 0$, and C is any positive constant, then there is an explicit positive number $C_1(\alpha, C)$ such that there is *at most one* solution of

$$\alpha - = \frac{p}{} < \frac{C}{q^{d}},$$

with $\max(|p|, |q|) > C_1$; hence this inequality has only a finite number of solutions. But one is unable to decide if this exceptional approximation exists, so one cannot *explicitly* bound all the solutions of the Diophantine equation, using Thue's method. Thus, one is unable to run a computer program to test all integers p, q with $|p|$, $|q| < D$ for an explicit constant D, computable directly from the equation, to get a complete list of solutions of our Diophantine equation. But one could (in principle) do this to obtain a list of solutions, such that at most d solutions are missing (one for each root α_r). This state of affairs is expressed by saying that Thue's method is not *effective*.
An effective decision procedure for finding solutions of certain Diophantine equations (including the Thue equation, but not the more general equations considered by Siegel) has been found by Baker and others; see Baker, A., '*Transcendental Number Theory*', Cambridge Univ. Press, Cambridge, 1975.
14. See Hartshorne, R., *Algebraic Geometry*, Grad. Texts in Math. No. 52, Springer-Verlag, New York, 1977, for results on algebraic curves, genus, etc.
15. We refer to the genus of the underlying Riemann surface of complex solutions as the genus of the equation. Equations of genus 1 describe *elliptic curves*; see Silverman, J. H., *The Arithmetic of Elliptic Curves*, Grad. Texts in Math. No. 106, Springer-Verlag, New York, 1986, for an introduction, and a survey of current research on Diophantine properties of elliptic curves.
16. Faltings, G., *Invent. Math.*, 1983, **73**, 349; see also Cornell, G. and Silverman, J. H. (eds), *Arithmetic Geometry*, Springer-Verlag, New York, 1986, which contains a translation of Faltings article into English, background for that article, as well as other related material.
17. A translation of Grothendieck's letter to the Swedish Academy, explaining the reasons for his refusal, can be found in the *Mathematical Intelligencer*, 1988.
18. See Varadarajan, V. S. (ed), *Harish-Chandra, Collected Papers*, Springer-Verlag, New York, 1983 (an Indian edition is published by Narosa, N. Delhi, 1985. Harish-Chandra was Langland's colleague at the Institute for Advanced Study in Princeton, until his death in 1983; Langlands has written an obituary for Harish-Chandra, which makes fascinating reading—see Langlands, R. P., 'Harish-Chandra', *Biog. Mem. Fellows of Royal Soc.*, 1985, **31**, 199.
19. See any of the books mentioned in Note 12 for the definition and many properties of p-adic numbers.
20. Ramanujan, S., *Trans. Cambridge Philos. Soc.*, 1916, **22**, 159. (see Hardy, G. H., Seshu Iyer, G. and Watson, G. M. (ed), *Collected Papers of Srinivasa Ramanujan*, Cambridge Univ. Press, Cambridge, 1927). Ramanujan's conjecture is that for any $\varepsilon > 0$, there is a positive constant C such that $|\tau(n)| < Cn^{11/2+\varepsilon}$. The mysterious exponent 11/2 is related to the *weight* of $\Delta(z)$, and to Weil's Riemann Hypothesis for algebraic varieties over finite fields, proved by Deligne. See Browder, F. E., (ed.) Note 24 for an exposition of Deligne's proof.
21. See Gelbart, S., *Bull. Am. Math. Soc.* (*New Ser.*), 1984, **10**, for an introduction to the Langlands program.
22. See C. Soulè, 'Gèomètrie d'Arakelov des surfaces arithmètiques', *Sèminaire Bourbaki*, No. 713, June, 1989, (to appear in *Astèrique. Soc. Math. France*), for an introduction.
23. This analogy is brought out in the book, Weil, A., *Basic Number Theory*, Springer-Verlag, New York, 1968.
24. See Browder, F. E. (ed.), *Mathematical Developments arising from the Hilbert Problems*, Proc. Symp. Pure Math. No. 28, Am. Math. Soc., Providence, 1976.
25. See Yu. Matijasevič, *Russian Math. Surveys*, vol. 27, No. 5, 1972, for a self-contained account of this work.

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A new algorithm for learning representations in Boolean neural networks

N. N. Biswas and R. Kumar
Department of Electrical Communication Engineering, Indian Institute of Science, Bangalore 560 012, India

A new algorithm for learning representations in a multilayer Boolean neural networks is presented. The algorithm depends on a theorem which states that any nonlinearly separable Boolean function can be expressed as a convergent series of linearly separable functions connected by the logical OR (+) and logical INHIBIT (−) operators. The formation of the series is accomplished by the implied minterm structure of linearly separable functions. The algorithm produces the representation much faster than the back propagation, and unlike the latter does not encounter the problem of local minima.

THE back propagation (BP) algorithm developed by Rumelhart *et al.*[1] suggests a new way to explore good representations. It is also the most extensively used learning algorithm for complex, multilayer systems. Among many networks where back propagation has been successfully applied, there is a class of networks where the input and output vectors are strings of binary bits, 0 and 1. In such networks, called Boolean neural networks by us, the representation obtained by the BP algorithm becomes a logic circuit implemented by the familiar threshold gates[2,3] working as hidden and output units. In the terminology of logical design and switching theory of computer science and engineering, the output vector becomes the output Boolean function, and the input state vectors which are binary combinations of input variables are known as fundamental products or minterms. The output Boolean function can, therefore, be depicted in a truth table or may be expressed as a sum of minterms[3,4]. Boolean functions which can be realized by a single threshold gate are linearly separable (LS) functions[2,3]. However, quite often the desired output function is not LS. In such a case the output function can be expressed as a convergent series of LS functions, given by a new theorem stated and proved in this paper. Based on this theorem and the implied minterm structure (IMS)[5] of LS functions, a new algorithm for learning good representations of Boolean neural networks is being presented in this paper. As we have discussed later, the algorithm does not have many shortcomings of the BP, and promises to provide a powerful alternative to BP for the Boolean neural networks.

While expounding the BP algorithm, Rumelhart *et al.*[1] have discussed in their paper seven problems, namely, XOR, parity, encoding, symmetry, addition, negation, and the T–C problem. In all these except the T–C problem, the learning network can be straightaway classified as Boolean. There are many other applications of learning, where the information from the outside world are encoded into binary bits by the input units of the learning network. Hence, Boolean networks, although a subclass of all types of neural networks, form undoutedly the most predominant and significant subclass. Therefore, an algorithm without many shortcomings of the BP although applicable only to Boolean learning networks, has the promise of being a most extensively used algorithm.

Implied minterm structure

In order to introduce the implied minterm structure to the reader, we first define a few basic terms.

Definition 1

Given a Boolean function, the *ON set* is the set of minterms whose output is desired to be 1. Minterms belonging to the ON set will be called *on* minterms.

Definition 2

Given a Boolean function, the *OFF set* is the set of minterms whose output is desired to be 0. Minterms belonging to the OFF set will be called *off* minterms.

Definition 3

The *tabular form* of a given function is the ON set minterms written in their binary form. It may also be considered as a matrix where each row represents a minterm whose output is desired to be 1, and each column is headed by a variable. For example, the tabular form of the 5-variable function

$$F(x_1, x_2, x_3, x_4, x_5) = \Sigma\,(0, 4, 10, 14, 17, 21, 27, 31)$$

can be seen in Table 1*a* of the next section.

Definition 4

The number of 1s in the binary representation of a minterm is called its *weight*.

Definition 5

A Boolean function is called *positive* and *ordered*, if in every column of the tabular form of the given function, the number of 1s is not less than the number of 0s, and the ratios of the number of 1s to that of 0s are such that if r_i and r_j are these ratios of the ith and the jth columns respectively, then $r_i \geqslant r_j$ when $i<j$.

Any arbitrary Boolean function can be made positive and ordered by suitable permutations and/or complementations of its columns.

In a LS function, it has been shown that if a minterm m_i is realized by a set of weights and threshold, then there are minterms which will also be realized by the same set. If m_j is one such minterm, then m_i is said to imply m_j.

Definition 6

Let m_1 and m_2 be two minterms such that

$$m_1 = b_1 b_2 \ldots 0 \ldots b_n$$
$$m_2 = b_1 b_2 \ldots 1 \ldots b_n,$$

then m_2 is said to have been obtained from m_1 by *positive complementation.*

Such a positive complementation when applied to the least significant bit (b_n in our notation) of the minterm is called *elementary positive complementation.* Note that the minterm m_2, obtained from m_1 by elementary positive complimentation has a weight $w+1$, where w is the weight of m_1.

Definition 7

Let m_1 and m_2 be two minterms such that

$$m_1 = b_1 b_2 \ldots 0 \ldots 1 \ldots b_n \text{ and}$$
$$m_2 = b_1 b_2 \ldots 1 \ldots 0 \ldots b_n.$$

Then m_2 is said to have been obtained from m_1 by *positive permutation.* Note that in positive permutation, a 1 is shifted to the left and a 0 to the right, and the weight of m_2 is the same as that of m_1.

Positive permutation when applied to adjacent bits of a minterm is called a *unit positive permutation.*

It will now be obvious that in a positive and ordered function, if the minterm m_j has been obtained by unit positive permutations on m_i, and m_k has been obtained by elementary positive complementations on m_i, then m_i implies m_j and m_k. Also note that the implication relation is transitive, that is, if m_i implies m_j, and m_j implies m_k, then m_i implies m_k.

The IMS of 4-variable minterms is shown in Figure 1. The IMS is a graphical structure showing implications between the minterms. In this structure if m_i implies m_j by virtue of m_j being obtained from m_i by either elementary positive complementation or unit positive permutation, then m_j appears below or on the right of m_i (or sometimes in an angle in between these two directions).

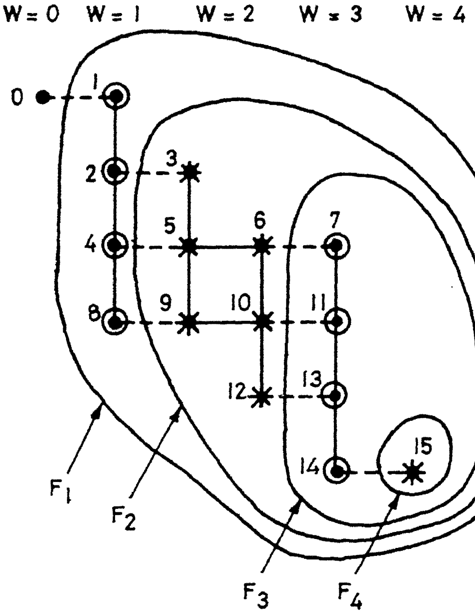

Figure 1. 4-Variable implied minterm structure, with on and star minterms of 4-variable odd parity function plotted on it. Also shown are nested compact zones of F_1, F_2, F_3, and F_4.

Solid lines (in Figure 1) are used to depict the implications due to unit positive permutations between two minterms of the same weight; and the dotted lines are used to show the implications due to elementary positive complementations, where implying minterm m_i has a weight w and the implied minterm m_j has a weight $w+1$.

To test the linear separability of a Boolean function, first make the function positive and ordered, and then plot the ON set minterms in the IMS structure. If the IMS now reveals at least one minterm that does not belong to the ON set of the function but is implied by one of the on-minterms, then the IMS of that function is said to have a *hole* in it and is therefore not compact. In this case the function is not LS. Hence, for a function to be linearly separable, its on-minterms must form a compact zone in the IMS, which may be defined as follows.

Definition 8

If a set of minterms in the IMS, whose every member has all (may be one or more) minterms implied by it also within the set, then the set of minterms is said to produce a *compact zone.*

The algorithm

The algorithm consists essentially of four procedures namely, TRANSFORM, ON-STAR, REALIZE and RESTORE.

We now solve two problems to explain the above procedures. Using the 4-variable odd-parity problem, we shall describe the procedures ON-STAR and REALIZE. Using the 5-variable mirror symmetry problem, we shall describe the procedures TRANSFORM and RESTORE.

4-Variable odd-parity problem

In this problem, the network learns to detect odd parity in bit strings of length 4. It can be seen that such strings of 4-variable minterms are 0001, 0010, 0100, 0111, 1000, 1011, 1101 and 1110. These have the decimal designations, 1, 2, 4, 7, 8, 11, 13 and 14. Hence the 4-variable odd parity Boolean function F_{OP} is given by the following sum-of-minterm form.

$$F_{OP}=\Sigma\,(1, 2, 4, 7, 8, 11, 13, 14).$$

It can be verified that the tabular form of this function is already positive and ordered. Now, plot the *on-minterms* of the function on the 4-variable IMS by circling the minterms (Figure 1). It is seen that the plotted on-minterms alone fail to produce a compact zone in the IMS. Hence, the function is not LS[5]. Therefore, to obtain an LS function we identify a compact zone which includes not only all on-minterms, but also some off-minterms. This produces the first compact zone, and represents an LS function F_1. The off-minterms in the first compact zone will be called *star-minterms* (shown by stars in Figure 1). Next we identify the second compact zone which is nested in the first compact zone. It must compulsorily include all star-minterms, and if need be, some on-minterms to make the zone compact. The second compact zone corresponds to the second LS function, F_2. The third compact zone (if any) will be nested in the second compact zone, and will compulsorily include all on-minterms within the second compact zone, and if need be, some star-minterms to avoid any hole. This produces another LS function, F_3. This process continues until the *n*th compact zone, which is a homogeneous zone (containing either only on or only star but not both types of minterms) is detected. In this function, the procedure terminates with the identification of the fourth LS function, F_4. It can now be easily verified that $F_{OP}=F_1-F_2+F_3-F_4$, where − and + are the logical INHIBIT and logical OR operators. The identification of the on and star minterms, and the compact zones is done by the ON-STAR procedure of the algorithm. The procedure REALIZE now finds the set of weights and thresholds of the identified LS functions. The procedure achieves this by several iterations, based on the principle of Dertouzos' vector[6].

For the 4-variable odd parity function, the weights of the four functions (see Figure 1), F_1 to F_4, turn out to be identical (namely 1, 1, 1, 1) and their thresholds are 0.5, 1.5, 2.5 and 3.5 respectively. Since, the functions F_1 and F_3 are excitory, they are connected to the output unit by weight 1. F_2 and F_4 are inhibitory and, therefore, are connected to the output unit by weight −1. The threshold of the output unit is always 0.5. The representation learnt by the network is shown in Figure 2. This representation happens to be identical to that of Rumelhart *et al.*[1]

We can now state and prove a new and significant theorem which is at the heart of this algorithm. We shall call this the linearization theorem, since it converts a non-linearly separable function into a series of linearly separable functions.

THEOREM 1

(*The Linearization Theorem*) *A non-linearly separable function F can always be expressed as a convergent series of LS functions* $F_1, F_2, \ldots, F_n$ *connected by the logical OR* (+) *and the logical INHIBIT* (−) *operators, such that,*

$F_1 > F_2 > \ldots F_n$, *and*
$F=F_1-F_2+\ldots+F_n$ *when n is odd, and*
$F=F_1-F_2+\ldots-F_n$ *when n is even.*

Proof: Without any loss of generality, we shall prove the theorem from the working of the algorithm while solving the 4-variable odd parity problem. It can be seen that the minterms of the first compact zone constitute the first LS function F_1. It consists of the on-

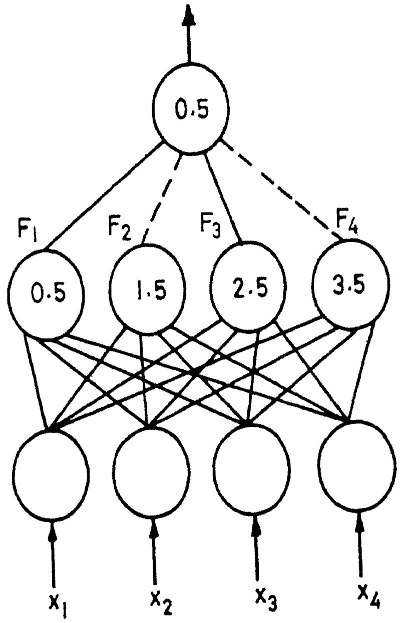

Figure 2. Representation for the 4-variable odd parity problem as obtained by the IMS algorithm. Solid lines show connections with positive weight, 1, and dotted lines connections with negative weight, −1. Gates are normally off, with output 0, and gets turned on producing an output 1, when the weighted sum exceeds the threshold shown in the circle.

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minterms and the star-minterms. It is now definite that whatever may be the distribution of the on and star minterms in the first compact zone, the on and star minterms constituting the second compact zone must be at least one on-minterm less than those of the first compact zone. Thus the set of minterms constituting the second compact zone will always be a proper subset of the set of minterms constituting the first compact zone. Hence $F_1 > F_2$. This will also be true for F_2 and F_3, and so on. Hence, generalizing $F_i > F_{i+1}$. It also follows from the algorithm, that the minterms of F_2 must be subtracted and those of F_3 must be added. In general, for all $i > 1$, F_i must be subtracted if i is even and F_i must be added if i is odd. The relation $F_i > F_{i+1}$ also proves that the series is convergent. QED

While solving the 4-variable parity problem, we explained the procedures ON-STAR and REALIZE. Let us now solve the second problem.

5-Variable mirror symmetry problem

In this problem the network learns to detect symmetry in a bit string of length 5. It can be seen that minterms, 00000(0), 00100(4), 01010(10), 01110(14), 10001(17), 10101(21), 11011(27) and 11111(31) have symmetrical bit patterns. In the sum-of-minterm form the 5-variable mirror-symmetry function can, therefore be written as

$$F_{\mathrm{MS}}(x_1, x_2, x_3, x_4, x_5) = \Sigma\,(0,4,10,14,17,21,27,31).$$

If this function is now plotted on the 5-variable IMS, and the compact zones identified, then we get 11 LS functions of theorem 1 as shown by the nested expression given below.

$$(0(1\text{–}3(4(5\text{–}9,16(10,17(11\text{–}13,18\text{–}20,24(14,21\\(15,22,23,25,26,28(27(29,30(31))))))))))$$

where the notation 1–3 means 1, 2, 3.

This will result in a representation having 11 hidden units. Although such a representation is correct, it is not economical. A significant reduction in hidden units can be achieved with the help of the procedure TRANSFORM. This procedure finds a permutation and/or complementation of the columns of the tabular form of the function, such that the function not only becomes positive and ordered, but also in its tabular form, the least minterm of the tabular form has the highest decimal designation. For example, the tabular form of the 5-variable F_{MS} function is shown in Table 1*a*. Table 1*b* shows the transform $(x_4, x_2', x_1, x_5', x_3)$, wherein the columns x_2 and x_5 have been complemented and the columns x_4, x_2', x_1, x_5' and x_3 become the 1st, 2nd, 3rd, 4th and 5th columns of Table 1*b*. The transform also changes the decimal designations of the minterms. Note that the least minterm of Table 1*a* is 0, and that of Table 1*b* is 10. This is the highest designation of the least minterm that may be obtained.

Table 1

(*a*)						(*b*)					
m_i	x_1	x_2	x_3	x_4	x_5	m_i	x_4	x_2'	x_1	x_5'	x_3
0	0	0	0	0	0	10	0	1	0	1	0
4	0	0	1	0	0	11	0	1	0	1	1
10	0	1	0	1	0	18	1	0	0	1	0
14	0	1	1	1	0	19	1	0	0	1	1
17	1	0	0	0	1	12	0	1	1	0	0
21	1	0	1	0	1	13	0	1	1	0	1
27	1	1	0	1	1	20	1	0	1	0	0
31	1	1	1	1	1	21	1	0	1	0	1
N(1)	4	4	4	4	4	N(1)	4	4	4	4	4
N(0)	4	4	4	4	4	N(0)	4	4	4	4	4

The minterms of Table 1*b* are now plotted on the 5-variable IMS, and the on and star minterms identified (Figure 3). It is interesting to note that now only two compact zones are found, corresponding to only two functions I_1 and I_2 of theorem 1. The REALIZE procedure now determines the weights of these two functions which turn out to be (2, 2, 1, 1, 0) for both I_1 and I_2. The RESTORE procedure now assigns these weights with proper signs to the input variables. Since in the transformed columns, the first column is headed by x_4, the first weight 2 is assigned to x_4. The second column is headed by x_2'. Therefore, the second weight with a negative sign is assigned to x_2. This way the weight vector (2, 2, 1, 1, 0) of the transformed variable $(x_4, x_2', x_1, x_5', x_3)$ becomes the weight vector (1, −2, 0, 2, −1) for the original variables $(x_1, x_2, x_3, x_4, x_5)$. Both the functions I_1 and I_2 have these weights. Thresholds are now computed with these weights.

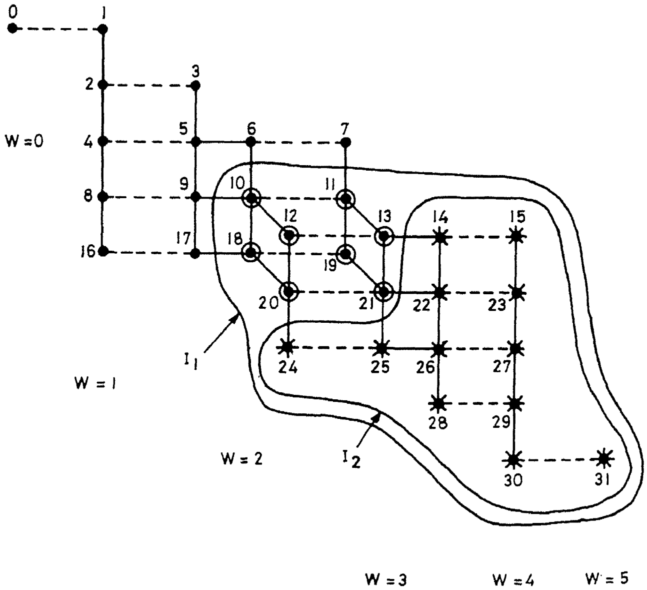

Figure 3. 5-Variable implied minterm structure, with on and star minterms of the 5-variable mirror-symmetry function plotted on it. Also shown are the nested compact zones of I_1 and I_2.

larger. However it is interesting to observe that a few volant young are still carried by their mothers.

At the time of breeding in several species of bats there is a high energy demand especially during the periods of advanced pregnancy and lactation. In addition to the cost of lactation the mother bats spend large additional amounts of energy soon after parturition in which mothers carry their infants continuously. The majority of bat species breed annually at energetically favourable periods when availability of insects for the nurture of the young and to meet their own demands of energy is maximum[4].

Since the newborn bats are hairless, sightless and flightless the mothers take care of their infants. The young never leave the nipple or pubic teats of the mothers during their early stage of life and may cling to the body of the mothers even while the latter forage[1]. Since the cave is a well-protected area, a few mothers of *H. speoris* leave their infants even at the newborn stage inside the cave to forage[5]. The mother–young relations progressively decline and thus more young bats are left behind in the cave as they become older (Figure 1). However it is of great interest to note that a few volant young (forearm length is about 40 mm) were still carried to the foraging areas. Even though this process increases the wing loading of mothers[3] the volant young must be highly benefitted by it. They practice the inborn and ingenious method of echolocation by following their mothers at foraging areas[6]. The volant young are able to emit the adult's type of CF–FM echolocation sounds of 135 kHz[7]. Brigham and Brigham[8] and Vaughan and Vaughan[9] have reported for temperate species of insectivorous bats evidence for association between mother bat and its young during and after foraging. In the case of the African yellow-winged bat *Lavia frons*[9] each young shared its parents foraging territory, synchronized its grooming and foraging periods with those of its parents and periodically huddled against its mother while roosting until at least 50 days after its first flight. Thus the relationship between mother and infant includes not only lactation but also training and practice the mother imparts to infants to navigate in the foraging areas dexterously using the echolocatory machinery. However we have no information as yet that the same infants get carried by the same mother bats on a daily basis. If that is not the case then one can account for volant subadults which are left behind. We can also then believe that being taken for the 'acquaintance flights' is a feature that applies to all subadults and is thus a part of their training and growing up.

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Studies on interrelationship between different anaerobic bacteria in biogas digester

S. V. Kulkarni and S. H. Godbole*
Department of Physics, Shivaji University, Kolhapur 416 004, India
*MACS Research Institute, Law College Road, Pune 411 004, India

Studies on interrelationship between methanogenic sulphate-reducing and denitrifying bacteria were carried out in a anaerobic biogas digester. Most probable number of these bacteria, concentration of sulphate and nitrate in fermenting slurry, gas production and redox potential were compared for 52 days. It was observed that sulphate-reducing bacteria reduce initial sulphate content of the fermenting slurry to bring it to low level and denitrifying bacteria help to establish the anaerobiosis by reducing the redox potential through utilization of nitrate.

A large variety of microorganisms are involved in production of methane by anaerobic digestion of organic matter. Although only three types of microorganisms, viz. cellulolytic, acid-producing and methanogenic bacteria are directly involved in production of methane, there are some other species of bacteria also present in anaerobic ecosystem which affect methanogenesis.

Sulphate-reducing and denitrifying bacteria are of particular importance since they have been reported to inhibit methanogenesis when sulphate and nitrate respectively is available in the ecosystem. These bacteria have been reported to compete with methanogenic bacteria for their common substrates and thus inhibit methanogenesis[1–3]. It has also been reported[4,5] that when sulphate is depleted from the ecosystem sulphate-reducing bacteria help methanogenesis by interspecies hydrogen transfer.

All these studies have been carried out on marine sediment and lake sediments where methane production occurs naturally. It is also necessary to study the exact role of these bacteria in anaerobic biogas digester.

Experiments were therefore carried out to study the interrelationship between sulphate-reducing, methanogenic and denitrifying bacteria in a anaerobic batch digester charged with cattle dung.

Fresh cattle dung slurry having 10% total solid contents was subjected for anaerobic digestion for 52 days in a laboratory model of biogas digester. Sulphate and nitrate were estimated by turbidometric and colorimetric methods respectively[6], on every 4th day. Enumeration of methanogenic sulphate-reducing and denitrifying bacteria was also carried out on every fourth day by most probable number (MPN) method. Total volume of gas produced, the percentage methane and redox potential of fermenting slurry were measured every day throughout the experiment. All the experiments were carried out in the Department of Microbiology, MACS Research Institute, Pune.

It can be seen from Figure 1 that the MPN of methanogenic bacteria reached the maximum level on day 12 and then declined to reach the lowest level on day 48. Biogas production was evident from day 4 but methane was first detected on day 8, methane percentage of biogas remained between 55 and 63.2% during the period of digestion. The MPN of sulphate-reducing bacteria reached the maximum level on day 12 and then declined to reach the lowest level on day 52. The initial concentration of sulphate of 21 mM was reduced rapidly to 6 mm on day 8 and then gradually to 1 mM on day 24 with no further decrease during the subsequent course of digestion.

The MPN of denitrifying bacteria (Figure 2) reached the maximum level on day 12 followed by gradual decrease on day 40. It then remained constant during the subsequent course of digestion. The concentration of nitrate declined and reached the lowest level of 14 mM on day 20 and then remained constant throughout. The initial redox potential (E_h) was gradually reduced till day 24.

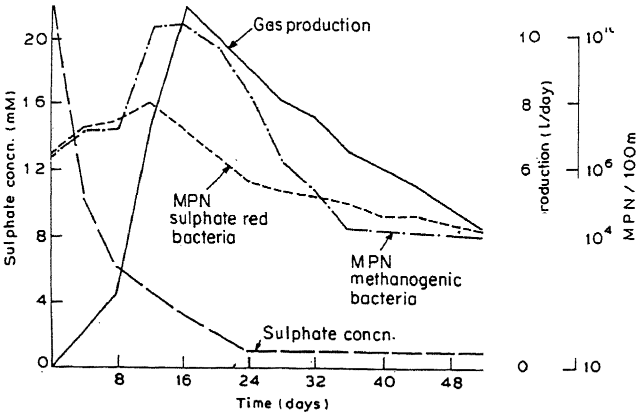

Figure 1. Ecology of batch anaerobic digestion of cattle dung with special reference to sulphate reduction.

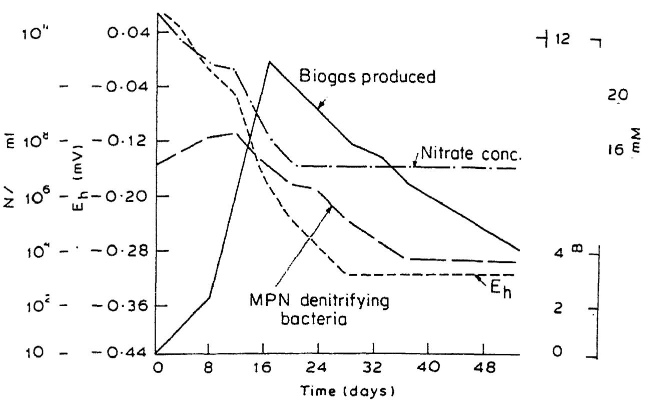

Figure 2. Ecology of batch anaerobic digestion of cattle dung with special reference to denitrification.

It has been reported earlier[3] that 10 mM concentration of sulphate inhibited methanogenesis in lake sediments. In the present studies it was observed that initial concentration of sulphate in cattle dung slurry was 21 mM.

It was seen that methane was detected only when sulphate concentration dropped to 6 mM on day 8. The quantity of biogas produced during the first seven days was relatively small and did not contain any methane. These results supported the findings of Cappenberg[2], and Martens and Berner[7], who have reported that methane was not produced in marine sediments until after the depletion of sulphate.

During the period of digestion initially there was rise in MPN of methanogenic and sulphate-reducing bacteria. Methane production increased to its peak when sulphate level was minimum. These findings indicate that during the initial non-methanogenic phase of anaerobic digestion sulphate-reducing bacteria play an important role in reducing the sulphate content of the fermenting slurry to bring it to a minimal level. The increase in gas production after six days might be due to interspecies hydrogen transfer between sulphate-reducing and methanogenic bacteria as reported by Mah *et al.*[4]

When the data on the denitrifying population, the nitrate content of the fermenting slurry, and the redox potential (E_h) during the course of digestion are compared, it becomes evident that a rise in MPN of denitrifying bacteria was concomitant with a drop in redox potential of the fermenting slurry. Since the methanogenic bacteria require very low redox potential for their growth it can be said that denitrifying bacteria help methanogenesis by reducing redox potential.

The present results thus establish the exact role of sulphate-reducing and denitrifying bacteria in the non-methanogenic phase. The sulphate-reducing bacteria reduce the sulphate content of the fermenting slurry, and the denitrifying bacteria help to establish the anaerobiosis by reducing the E_h through utilization of nitrate.

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The *ortho* cleavage of catechol by *Azotobacter chroococcum*

S. Balajee and A. Mahadevan
Centre for Advanced Study in Botany, University of Madras,
Madras 600 025, India

***Azotobacter chroococcum* utilized catechol as sole carbon source. Maximum growth was supported by 2 mM. Catechol was cleaved by the *ortho* pathway mediated by catechol 1, 2-dioxygenase.**

In an effort to isolate efficient strains of *Azotobacter* that would rapidly cleave phenolic waste, we isolated a strain of *Azotobacter chroococcum* from Kalakad Reserve Forest, Tamil Nadu. Among the dihydric phenols which are substrates for ring cleavage, catechol is the most prominent one[1]. Azotobacters are known to cleave catechol by the *meta* pathway[2]. A study[3] of benzoate catabolism in *Azotobacter* sp. established the oxalocrotonate branch for *meta* cleavage of catechol.

A. chroococcum strain MSB1 was grown in nitrogen-free growth medium (mannitol, 5 g; K_2HPO_4, 0.03 g; $MgSO_4{\cdot}2H_2O$, 0.2 g; $Na_2SO_4{\cdot}10H_2O$, 0.2 g; $CaCl_2$, 0.01 g; $Na_2MoO_4{\cdot}2H_2O$, 0.005 g; $FeSO_4{\cdot}7H_2O$, 0.002 g; distilled water 1000 ml; pH 7.0) to which filter sterilized catechol at different concentrations was added. The cells were grown at 30°C at 125 rpm in an orbital shaker. After 3 days of incubation the mode of ring cleavage was determined by Rothera's reaction[4] and by the assay of catechol 1,2-dioxygenase[5].

Catechol was utilized by *A. chroococcum* after 8 h. Catechol at 2 mM was a better carbon substrate than at 5 mM; 10 mM was inhibitory, 20 mM was toxic (Figure 1). The generation time of the bacterium in 2 mM catechol was 4.7 h. Rothera reaction with catechol-grown cells yielded deep purple colour indicating the *ortho* cleavage of catechol and the presence of keto compounds. Catechol-grown cells displayed catechol 1,2-dioxygenase activity as evidenced by decrease in O.D. at 278 nm, the absorption maxima of catechol and increase in 258 nm, indicating *cis,-cis* muconic acid formation (Figure 2, *a*). The specific activity of the enzyme was 1.8. No catechol 2,3-dioxygenase activity was detected.

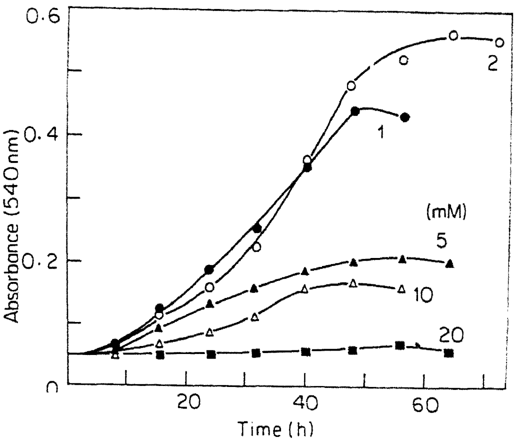

Figure 1. Growth of *A. chroococum* in catechol.

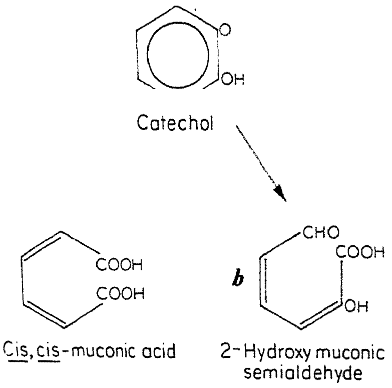

Figure 2. Ring cleavage of catechol. *a*, *Ortho* cleavage. *b*, *meta* cleavage.

This is the first report on the *ortho* cleavage of catechol by *A. chroococcum* in contrast to the existing reports on the *meta* cleavage (Figure 2, *b*). Not surprisingly this bacterium also efficiently cleaved 2,4-D (ref 6), which could be attributed to the presence of the *ortho* enzyme, since *meta* enzyme is irreversibly inactivated[7].

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Autosomal chromosomes carrying sex genes in *Momordica dioica* Roxb.

U. C. Jha
Department of Botany, North-Eastern Hill University, Shillong 793 014, India

Cucurbits display a variety of sex forms ranging from hermaphroditism to dioecism through monoecism and other intermediate type. Precocious separation of bivalents in the species during meiotic phase cannot be explained on the basis of heteromorphic nature of chromosome as all the chromosomes were smaller in size. The character indicates its incipient heteromorphy in which total chromosome length in not taking part in sex expression, rather the autosomes carrying sex-deciding genes. This species exhibits intermediate stage of sex mechanism where one pair of autosomes is responsible for sexual dimorphism.

Cucurbits exhibit a variety of sex forms. In the dioecious species of the family, sex mechanism has been explained entirely on the genic basis of sexual dimorphism without any cytological manifestation, e.g. *Luffa echinata*[1]. In some dioecious species it has been studied on X/Y chromosome basis (*Coccinia indica*) where distinctly heteromorphic pair of chromosomes is present[2]. An intermediate type of sex mechanism has been reported in *Trichosanthes dioica*[3] on the basis of homologus chromosome complements expressed during microsporogenesis in the male which is an indicative of incipient type of sexual dimorphism.

Momordica dioica is a perennial, rhizomatous and distinctly dioecious species of the family Cucurbitaceae[4]. Somatic chromosome number[5,6] is $2n = 28$ and heteromorphic bivalents are reported earlier[7]. But this has not been confirmed in later studies. The present paper deals with the autosomal behaviour carrying sex genes in diploid and induced polyploid cytotypes of *M. dioica* and is being reported for the first time.

For meiotic analysis young staminate floral buds were fixed in 1 : 3 acetoalcohol in both the cytotypes. In diploid cytotype it has been found that one pair of chromosomes showed precocious separation at late metaphase I (Figure 1, *a*). All the chromosomes were found to be arranged on the equatorial plane except two that separated early and moved far from the equatorial plane. Polyploidization was induced in the species by colchicine treatment[8]. Autotetraploid cytotype showed bivalent and quadrivalent associations. Segregation behaviour in one pair of chromosomes (Figure 1, *b*) has also been met with during metaphase and anaphase. Separation pattern of chromosomes in both the cytotypes remained the same.

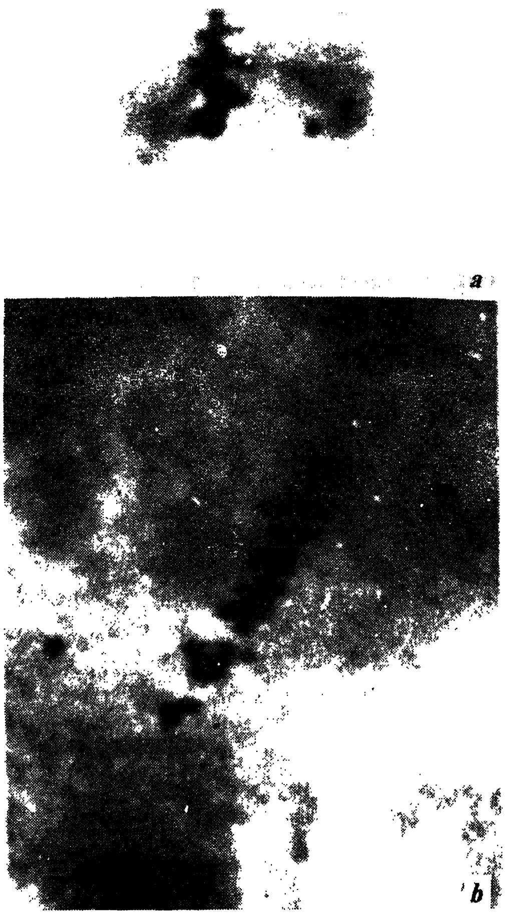

Figure 1. *a*, Metaphase of meiosis in diploid *M. dioica* with precocious separation. *b*, Metaphase in colchiploid shows early separation of chromosomes.

Precocious separation of bivalents during metaphase and anaphase I and II meiosis in the diploids and autotetraploids cannot be judged on the basis of heteromorphic nature of the chromosomes, because in both the cases chromosomes are smaller in size and do not differ in morphology. Hence, sex mechanism in *M. dioica* does not follow the X/Y chromosomal basis. Precocious separation during metaphase or non-disjunction behaviour of chromosomes during anaphase can be explained on the basis of incipient heteromorphic pair of chromosomes which revealed similar morphology but differs in segregating pattern during the meiotic phase[9]. It may be assumed that total chromosome length of such a homologous pair is not responsible for sex expression in this species as it is in *Melandrium album*[10] and *Coccinia indica*[11], rather the autosomes carrying sex-deciding genes in *M. dioica* favour the production of male and female dioecious plants; and the block of genes in staminate plants cause early separation of chromosome during metaphase and anaphase due to the heterogametic nature in male sex. In other way, the aberrant nature of one pair of chromosomes suggests that this pair carries sex-deciding genes without any heteromorphy. It indicates that *M. dioica* exhibits intermediate stage towards chromosomal basis of dioecism in which a pair of autosomes associated with sexual dimorphism are structurally homomorphic but the linkage group provides a very short homologous segment and a large differential one causing precocious separation during metaphase.

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Genotype-dependent response to *Azospirillum* treatment in yield and nitrogenase activity in *Brassica juncea* L.

P. S. Kesava Rao, V. Arunachalam and K. V. B. R. Tilak*
Divisions of Genetics, *Microbiology, Indian Agricultural Research Institute, New Delhi 110 012, India

Twelve advanced lines of mustard (*Brassica juncea* L.) were evaluated for response to treatment with *Azospirillum brasilense* in yield and a few components. Two lines gave yield increases with concomitant increases in nitrogenase activity and *Azospirillum* population. In general, there were desirable and significant correlations between plot yield, nitrogenase activity and $\log_e$ (*Azospirillum* population). The results point to the possibility of utilizing genotype-dependent response to *Azospirillum* in breeding programmes and also for exploring new avenues of *Azospirillum*-based cultural practices in sustaining improved productivity.

In the context of imperative need for increasing and sustaining productivity in oleiferous Brassicae, the utility of bio-fertilizing agents assumes crucical importance. *Azospirillum* has been reported to be a good microaerophilic nitrogen fixer in several plants[1,2]. Its potential to increase grain yields has been recorded in crops like sorghum, pearl millet, ragi and barley, though the magnitude of improvement varied with the crop and genotypes. The utility of such biofertilization in Brassica did not appear to have been examined or reported so far. This paper summarizes the results of a pilot study on the response of *Brassica juncea* to seed treatment with *Azospirillum brasilense*.

Ten advanced lines of *B. juncea* developed in the Oilseeds Unit of the Indian Agricultural Research Institute, and the two checks, Pusa Bold and Pusa Barani formed the material. Seeds of the lines were coated with *A. brasilense* following the procedure outlined by Subba Rao *et al.*[3] Thus in each line there were two treatments—control, and treated with *Azospirillum*. The material was grown in a split-plot design with three replications, with the lines allotted to main plots and the two treatments to sub-plots. The plot size was five rows of 5 m length, with inter-row space of 60 cm and inter-plant distance of 10 to 15 cm. The crop was raised under normal agronomic and cultural practices. The crop was free of diseases; but aphids were controlled by timely application of the insectiside, Rogor.

Observations were recorded on plot yield (g) and on the following characters on samples of five plants, with mean values being used for statistical analysis: plant height (cm), number of primary branches, number of secondary branches and biomass (g). The presence of *Azospirillum* in the rhizosphere soil was detected by the most probable number (MPN) method[4]. The bacterial population in the endorhizosphere was estimated by macerating one gram of fresh roots after surface-sterilizing the roots with 0.1% chloramine-T for 30 min and making to 10-fold serial dilutions in sterile distilled water. The MPN counts were taken according to Alexander[5] and the population expressed as per g dry soil or per g fresh weight of roots. The cell count values were transformed to log scale to remove non-normality for further analysis. The acetylene reduction assay suggested by Hardy *et al.*[6] was used to assess the nitrogenase activity in excised roots.

The variation among the lines was significant for plot yield and the three characters—$\log_e$ (*Azospirillum* population in rhizosphere, RHS), $\log_e$ (*Azospirillum* population in endorhizosphere, ERS) and nitrogenase activity (NGA). Treatment variation and the line × treatment interaction were significant for biomass, ERS and NGA; they were not significant for plot yield.

The range of variation among the lines was high in the control lines for all characters except primary and secondary branches (Table 1). *Azospirillum* treatment enhanced the mean and the range of variation still further. Overall, plot yield showed a little but non-significant depression under treatment. In general, the coefficient of variation (CV) for the treated lines was much higher than the corresponding values for control, though for *Azospirillum* cell count and nitrogenase activity there were either no differences or a nominal decrease in the CV of treated lines.

However, a few cultures responded to the *Azospirillum* treatment and could show significant improvement over control for primary branches, biomass and plot yield (Table 2). The improvement was relatively higher for other

Table 1. Mean and range of variation for various traits in *B. juncea*.

Character	Control			Treated			Genetic variance among lines
	Range	Mean	CV	Range	Mean	CV	
Plant height (cm)	148–204	173	9	151–208	174	10	228.27
Primary branches	5–7	6	8	6–7	6	7	0.0012
Secondary branches	10–17	13	15	19–18	13	20	0.55
Biomass (g)	68–127	106	18	78–176	110	27	64.96
Plot yield (g)	1220–2987	2391	22	1267–3060	2291	25	0.27
$\log_e$ (*Azospirillum* population)							
Rhizosphere (per g soil)	9–14	12	15	15–23	18	12	2.95
Endorhizosphere (per g fresh root weight)	7–10	8	11	11–16	12	12	0.43
Nitrogenase activity (μmol C_2H_2/h/g fresh root weight)	4–13	6	48	6–22	11	39	12.10

Table 2. Significant improvement (%) in some characters with application of *A. brasilense* in *B. juncea*.

Character	Treated > Control		Treated < Control	
	Cultivar	Improvement	Cultivar	Improvement
Primary branches	DIRA 326	30	—	—
	DIRA 329	20	—	—
	DIRA 333	22	—	—
Secondary branches	DIRA 326	55	DIRA 335	24
	DIRA 329	23	Pusa Bold	19
	DIRA 333	43	Pusa Barani	29
	DIRA 337	24		
Biomass	DIRA 326	160	DIRA 335	31
			Pusa Bold	30
Plot yield	DIRA 313	11	DIRA 18	26
	DIRA 335	8	DIRA 344	12

characters than for plot yield. The yield increase was not accompanied by simultaneous improvement in other characters. Some lines showed significant decrease in the values of secondary branches, biomass and plot yield under *Azospirillum* treatment. The results are thus suggestive of a genotype-dependent response to *Azospirillum* treatment.

The observed improvements could be associated with significant and desirable correlation between yield (YLD) and some of the component characters defining increased nitrogenase activity. In particular, RHS, NGA and ERS were worth mentioning (r: YLD–RHS = 0.546*; YLD–NGA = 0.457*; RHS–ERS = 0.896*). Further, the regression of plot yield on nitrogenase activity was significant (at $P = 0.05$) under *Azospirillum* treatment ($b = 1.638$*) and not significant under control ($b = 2.027$, not significant). In turn, the regression of the increase in nitrogenase activity in lines on the increase in RHS was significant ($b = 5.428$*). Thus the results would suggest that *Azospirillum* count in rhizosphere could have accentuated nitrogenase activity resulting in better nitrogen remobilization and thereby in increased yields. Such a view is also supported by the desirable and positive increases in the values of RHS, ERS and NGA in cultures that recorded increases in plot yield (Table 3). But such increases were not observed in the relatively high-yielding checks, Pusa Bold and Pusa Barani, which recorded high increases in nitrogenase activity. It is possible that the *Azospirillum* population had already reached the required threshold in the check varieties; as a consequence, further increases in cell count and hence nitrogenase activity could not result in proportionate increases in yield. By the same logic, lines like DIRA 313, DIRA 335 which did not possibly reach such thresholds in *Azospirillum* population and nitrogenase activity could record appreciable yield increases (Table 3). Thus the observation that there is genotype-dependent response for *Azospirillum* treatment in *B. juncea* gains further ground. Earlier work has also shown differential response to *Azospirillum* in varying growth environments and various crops[7,8]. In particular, *Azospirillum* treatment combined with low doses of nitrogenous fertilizer gave responses equivalent to those obtainable under high doses of N application, entailing considerable saving in fossil fuel

Table 3. Increase in mean values of some characters in *Azospirillum* treatment over control in specific lines of *B. juncea.*

			$\log_e$ (*Azospirillum* population)		
Line	Biomass	Plot yield	Rhizosphere (per g soil)	Endorhizosphere (per g fresh root weight)	Nitrogenase activity
DIRA 313	21.8	0.21	5.92	4.94	4.75
DIRA 335	− 34.7	0.23	6.36	3.30	7.50
Pusa Bold	− 32.9	− 0.21	6.61	6.32	6.59
Pusa Barani	− 11.0	− 0.14	9.05	8.60	9.17
lsd	43.78	0.38	2.44	2.05	2.87

depleting chemical fertilizers. With such possibilities, breeding for higher productivity in *B. juncea* begets an expanded horizon in which (i) increases due to combined application (of low doses) of N with *Azospirillum*, and (ii) exploitation of genotype environment-dependent *Azospirillum* response becomes feasible propositions to reckon with.

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27 December 1989

A novel agar-based food attractant for uzi fly (*Exorista sorbillans*)

S. Sighamony, I. Anees, T. S. Chandrakala and Kaiser Jamil
Biology Division, Indian Institute of Chemical Technology,
Hyderabad 500 007, India

The use of attractants for trapping insects is well known. In experiments with the uzi fly, *Exorista sorbillans*, whose larval stage is endoparasitic in the silkworm *Bombyx mori*, we found that odoriferous compounds like citral and vanillin were good attractants. The agar-based food attractant suggested in the present study for trapping uzi fly contains jaggery, D-maltose, citral, vanillin and weak formaldehyde. These compounds are also safe to non-target organisms. The results suggest that this food formulation can be employed as bait to trap uzi flies.

THE introduction of uzi fly (*Exorista sorbillans* Wied; Tachinidae: Diptera), a serious pest of the silkworm *Bombyx mori* L., into this country illustrates the need for a constant vigil to prevent the spread that can play havoc in silk industry[1–4]. Attractants can be of great aid in the early detection of a non-indigenous species before it gains a firm foothold. Interest in insect attractants has also been spurred by the possibility that they may provide at least a partial answer to the growing problem of harm to non-target species.

Insect attractants may be used for two general purposes: for surveys and for aiding in the control of insect infestations. These methods are environmentally safe and sound and more popular in recent times. Experience has shown that attractants may be found in compounds that occur in the natural environment of the insect but majority of known attractants are associated with insect feeding. Many studies and attempts[5–7] have been made towards controlling uzi fly populations, but no practical or effective area-wide abatement measures have been formulated so far.

In the present study, diet-based formulations have been tried for the first time as a control strategy of uzi fly infestation.

Uzi-pupae were procured from the Karnataka State Sericulture Development Institute, Bangalore and were allowed to emerge in the laboratory in netted cages of 45 × 45 × 45 cm. Agar-based food attractants were formulated using jaggery as the source of food because jaggery (10 g) and agar powder (3 g) heated in 100 ml water, cooled and set in petri dishes attracted uzi flies. This was used as the base attractant (FA) for all experiments. In order to achieve greater attractiveness sugars like glucose, fructose, maltose and sucrose were mixed separately with the agar base medium (in different formulations, Table 1). In the literature, sugar, protein hydrolysate or cereal products were used as food lures[8] along with a toxicant in formulating baits and in testing several natural products as attractants for *Musca domestica bulleta*[9], a 10% aqueous solution of

Table 1. The agar base food formulations as attractants for uzi flies.

	Formulations					
Food component	a	b	c	d	e	f
Agar	A	A	A	A	A	A
Jaggery	A	A	A	A	A	A
D-maltose	A	A	N	N	N	A
D-Glucose	N	N	A	N	N	N
Sucrose	N	N	N	A	N	A
Fructose	N	N	N	N	A	A
Vanillin alone	A	N	N	A	A	N
Vanillin in ethyl alcohol	N	A	A	N	N	A
Citral	N	A	N	A	N	A
Scoring	++	+++	+	++	+	+++

+, Mild attraction; ++, Good attraction; +++, Highly attractive; A, Added; N, Not added.

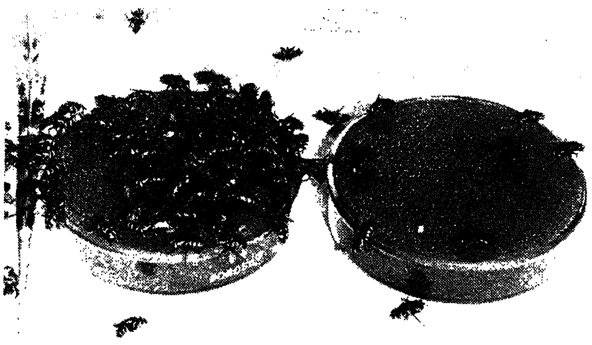

Figure 1. Photograph showing the higher attractiveness of the food attractant in comparison to the basal attractant.

malt extract was reported to be most effective. In our investigation chemical compounds of natural or synthetic origin were screened and incorporated in the selected formulated diet (Table 1). Among the materials tested, vanillin, (3-methoxy-1, 4-hydroxybenzaldehyde), citral (3,7-dimethyl-2, 6-octadienal) and ethyl alcohol gave positive response. The addition of weak formaldehyde vapours, in the final standard food attractant served as antifungal agent and also as an attractant. This chemical has been reported as a stimulant factor for house-fly[10].

All the food attractants prepared were screened essentially by counting the number of caged flies attracted by food in the petri dishes and the total number of flies in the observation cages. The observations were continued for 4–6 h at 27 ± 1°C and 50–55 RH. Per cent attractancy was calculated and scored.

In general food lures are used in combination with a toxicant to help combat injurious species. In the case of uzi flies, which parasitize silkworms, insecticidal sprays are not advisable since they can harm silkworms. The food attractant has been formulated by comparing the attractiveness. Addition of citral, and vanillin in ethyl alcohol greatly increased the attractiveness to uzi flies. The proteinaceous lure[11] developed for oriental fruit flies and for both sexes of melon flies became the standard attractant. Methyl lineolate, the main constituent of pine needle juice was reported a potent food lure for the pine weevil[12].

A diet formulation having citral caused immediate attractiveness whereas FA prepared by adding 2% vanillin in ethyl alcohol worked out as an arrestant for the flies since they could not move away from the source. Attraction to citral could be due to similarity of its odour to something in the natural environment of the flies. The attraction of mulberry leaves to silkworms[13] may be due to the presence of certain terpenes as food stimulants, and citral is one of them. Citral[14] has also been used as an attractant for Japanese beetles and cooling moths. Vanillin was shown[8] to attract oriental fruit flies. In olfactometer tests, ethyl alcohol/malt extract[10] headed a list of attractants for house flies, the effect was potentiated by weak formaldehyde vapour.

The attractiveness of the standard food attractant to both sexes of uzi flies was 90% which exceeded the sum of those exhibited by the individual ingredients. It is seen that odoriferous products like citral and vanillin influence the chemosensory behaviour of the uzi and making it orient itself to the food attractants. These volatile compounds in minor quantities are environmentally safe and sound for all non-target organisms.

The present results suggest that the food composition can be employed as baits to trap uzi flies.

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Baculoviruses from two lepidopterans: *Eupterote cardamomi* and *Agrotis ipsilon*

R. J. Rabindra, S. Jayaraj, S. Parameswaran
K. Natarajan and A. M. Huger*
Centre for Plant Protection Studies, Tamil Nadu Agricultural University, Coimbatore 641 003, India
*Biolog. Bundesanstalt, Institute for Biologische, Schadlingsbekampfung, D-6100 Darmstadt, FRG

A nuclear polyhedrosis virus (NPV) from the cardamom hairy caterpillar *Eupterote cardamomi*, which infests cardamom, and a granulosis virus (GV) from the black cut worm *Agrotis ipsilon*, which infests potato, were isolated. Electron microscopic observations showed that the *E. cardamomi* NPV is a multiple nucleocapsid enveloped virus. It was highly virulent against third-instar larvae of *E. cardamomi*. The *A. ipsilon* GV produced only 20% mortality in *A. ipsilon* larvae. Electron micrographs of capsules revealed a single rod-shaped virion per capsule.

DURING a survey of the Western Ghats in the State of Tamil Nadu in India for the occurrence of entomopathogens, two baculoviruses, a nuclear polyhedrosis virus (NPV) from the cardamom hairy caterpillar *Eupterote cardamomi* and a granulosis virus (GV) from the black cut worm *Agrotis ipsilon*, were isolated. There seems to be no previous reports on the natural occurrence of NPV in *E. cardamomi*. The GV of *A. ipsilon* however has been included in the catalogue on viral diseases of insects[1]. But the virus has not been previously reported from India. In field experiments, however, the GV from *Agrotis segetum* was reported to be very effective against larvae of *A. ipsilon*[2].

E. cardamomi is a seasonal pest on cardamom, often causing extensive defoliation during June–July. During 1986, the occurrence of diseased larvae with symptoms characteristic of NPV was noticed among field populations of *E. cardamomi* on cardamom. Smears of diseased larvae examined under the phase contrast microscope revealed the polyhedra in the nuclei of cells of fat body and tracheal matrix. The polyhedra ranged from 0.8 to 1.5 μm with a mean ($n = 20$) of 1.21 μm ± 0.16 (Figure 1, *a*). Electron micrographs of alkali (0.05 N NaOH)-treated polyhedra stained with phosphotungstic acid (PTA) showed that the virus is a multiple nucleocapsid enveloped NPV (Figure 1, *b* and *c*). The nucleocapsids measured 295 × 40 nm. Inoculation of third instar larvae of *E. cardamomi* with the virus produced 100% mortality in 3–5 days. Due to its high virulence, the virus may prove to be a promising agent in the control of *E. cardamomi* on cardamom, an important spice crop in the hills of Tamil Nadu.

The black cut worm *A. ipsilon* is a serious pest of potatoes in India. A nuclear polyhedrosis virus has been reported

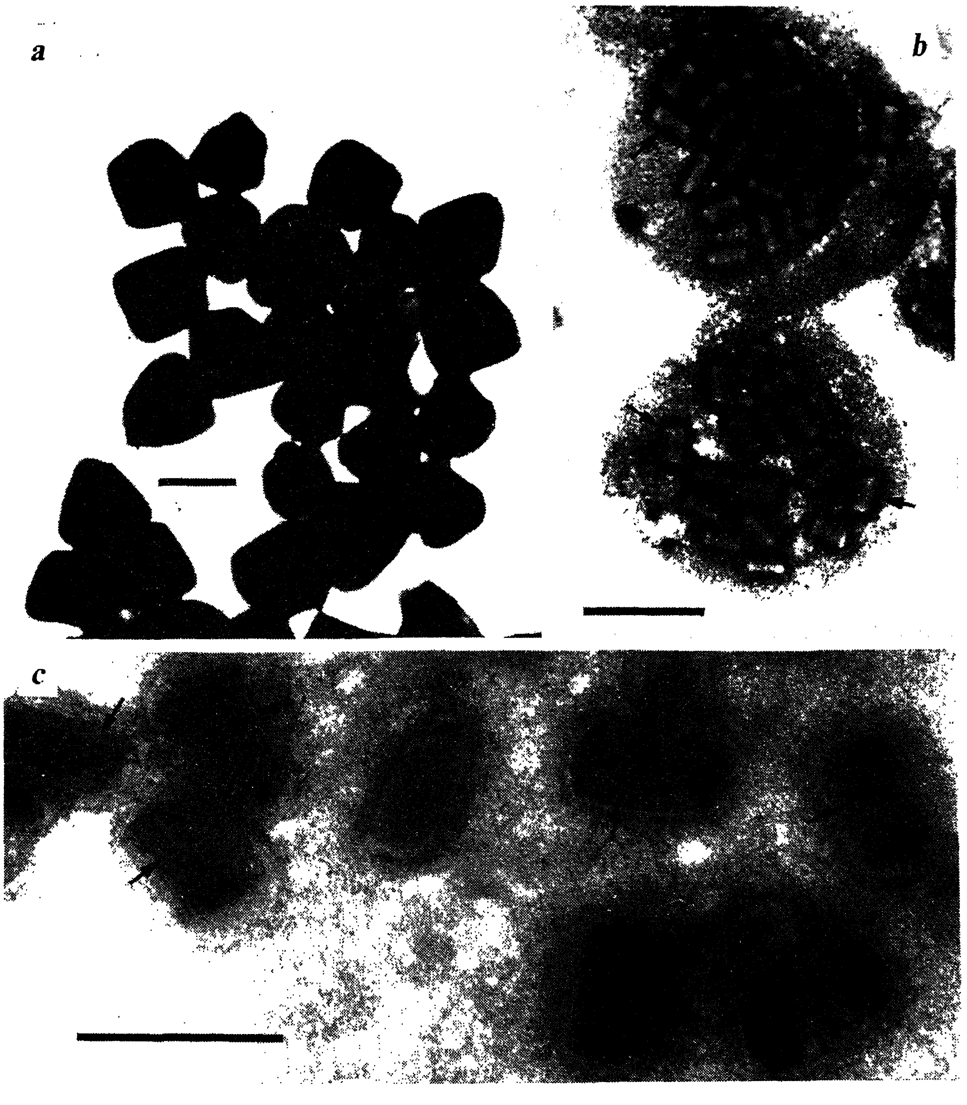

Figure 1. Electron micrographs of a nuclear polyhedrosis virus of *Eupterote cardamomi*. ***a***, Purified polyhedral virus occlusion bodies stained with PTA. Bar = 1 μm. ***b***, Two polyhedral virus occlusion bodies briefly exposed *in situ* to 0.05 N NaOH and negatively stained with PTA; the polyhedrin is partially dissolved, thus exhibiting enveloped bundles of virus nucleo-capsids (arrows). Bar = 1 μm. ***c***, Higher magnification of bundles of rod-shaped virus nucleocapsids (arrows) common to a single envelope, negatively stained with PTA. Bar = 500 nm.

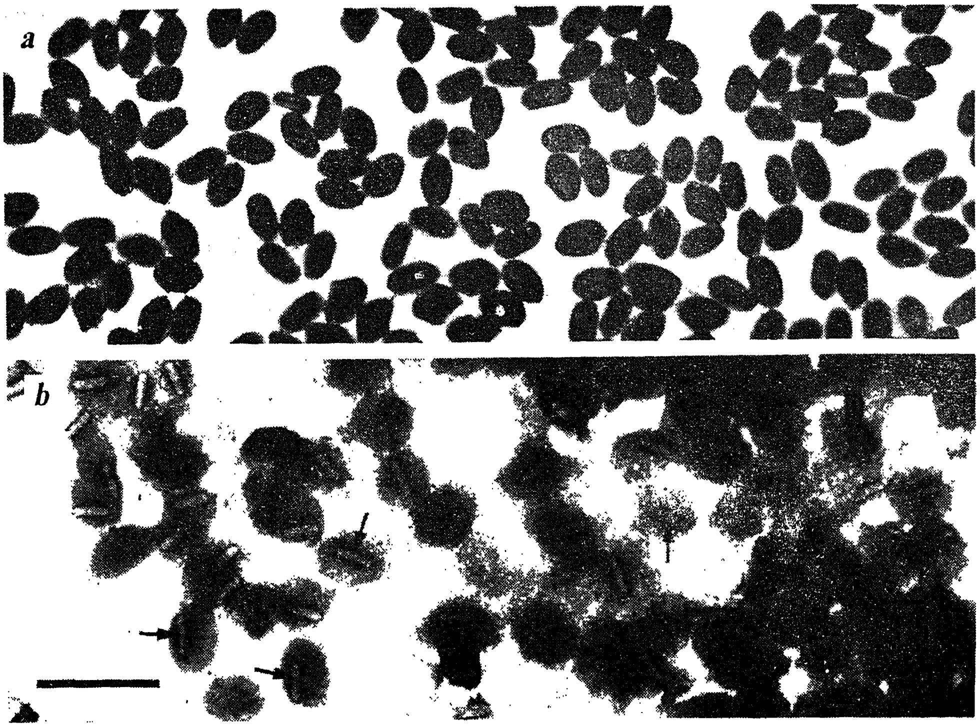

Figure 2. Electron micrographs of a granulosis virus of *Agrotis ipsilon*. ***a***, Capsule-shaped virus occlusion bodies stained with PTA. ***b***, Partially dissolved (0.1 N NaOH) capsules, each displaying a single rod-shaped virus particle (arrows), negatively stained with PTA. Bar for ***a*** and ***b***= 1 μm.

from *A. ipsilon* earlier[3]. During 1986, a few larvae of *A. ipsilon* collected from potato fields in two different hill tracts in Tamil Nadu—Nilgiris and Kodaikanal—were found to be infected with a granulosis virus. The virus, however, was not found to be very virulent. Upon inoculation of third instar larvae of *A. ipsilon* with a heavy dose of capsules by the diet-surface contamination method, only 20% mortality could be obtained 10–12 days after inoculation. There were no significant differences in mortality rates when the inoculated larvae were maintained at room temperature (22–31°C) or at 20 ± 1°C.

Paraffin sections of larvae stained with the modified azan staining technique[4], revealed the presence of capsules in the fat body cells. Light infections of cells of hypodermis and tracheal matrix could also be seen, and hence the virus can be placed under the polyorganotropic type[5]. Sections stained with Heidenhain's haematoxyli[6] showed a dark blue network in the highly hypertrophied nuclei characteristic of granulosis infections.

Electron micrographs of capsules briefly treated with 1/10 N NaOH and negatively stained with PTA revealed a single rod-shaped virion per capsule (Figure 2, *b*). The size of the capsules averaged 420 × 225 nm (Figure 2, *a*), and that of the virions 300 × 65 nm.

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Successful transmission of *Leishmania donovani* in Indian langurs (*Presbytis entellus*)

Anuradha, R. Pal, P. Y. Guru, J. C. Katiyar and N. Sethi

Divisions of Parasitology and Toxicology, Central Drug Research Institute, P. B. No. 173, Lucknow 226 001, India

Successful transmission of *Leishmania donovani* infection in Indian langurs (*Presbytis entellus*) has been achieved following single intravenous inoculation of 1×10^8 amastigotes. The infected animals survived for 105 ± 5 days. The parasite count following natural death/autopsy was found to be 6–39, 3–7 and 1–13 per 100 cell nuclei in spleen, liver and bone marrow respectively. The haematological picture in acute phase of infection (day

90 p.i.) revealed anaemia (due to lowering Hb%, RBC count and Hct%) and marked dipression in the total as well as relative counts of polymorphs and platelets — a picture identical to kala-azar of man. The study suggests that langurs are suitable non-human primates for various experimentation in visceral leishmaniasis.

SEVERAL rodents (mice, guinea pigs, hamsters)[1], carnivores (dog)[2] and non-human primates (opossum, *Didelphis marsupialis*; owl monkey, *Aotus trivirgatus* and squirrel monkey, *Saimiri sciurea*)[3–5] have been found susceptible to *Leishmania donovani*, the causative agent of dreaded protozoan disease, visceral leishmaniasis. The parasite is highly pathogenic to some of these species[5], killing the hosts within 50–60 days of infection, whereas in others, the results are not corroborative with those in the target host, man. The Indian langur (*Presbytis entellus*), which is phylogenetically and physiologically close resemblance to man, has not as been explored as a host for *L. donovani*. These monkeys, if found susceptible, could well become the most favourite experimental hosts for leishmaniasis, and will be comparatively ecnomical. Our efforts have led to successful transmission of *L. donovani* in langurs. This is perhaps the first report in this direction.

The strain of *L. donovani* (MAN/IN/80/Dd8), originally isolated in 1979 from Bihar, was obtained through Dr P.C.C. Graham, Imperial College, London. The LD bodies (amastigotes) were isolated from heavily infected hamster spleen[6] and suspended in locke's solution to a concentration of 1×10^8 amastigotes per 0.1 ml.

Four young male Indian langurs weighing 3–4 kg were each inoculated on the forearm with 1×10^8 amastigotes intravenously. The animals were maintained under standard laboratory conditions and were given food and water *ad libitum*. These were constantly observed for general condition during the experimental period. The haematological parameters (Hb, TLC, DLC, RBC, Hct, MCV, ESR and platelet count) were assessed on days 35 and 90 p.i. The parasitic counts were assessed from spleen, liver and bone marrow[6] when the langurs died.

Around 2 months p.i., all the monkeys became listless and weak. The deterioration in their condition continued till the death occurred. Blood screened on day 35 p.i. did not reveal any diversion from normal values (Table 1). However, by day 90 to day 110 p.i. there was significant lowering of haemoglobin, RBC and Hct. There was marked depression in the total as well as relative counts of polymorphs and platelets and elevation in lymphocytes. The parasite counts in spleen, liver and bone marrow were 6–39, 3–7 and 1–13 respectively per 100 cell nuclei (Figure 1, *a–c*). Skin was devoid of amastigotes.

The splenic aspirate from infected langurs was cultured *in vitro* in NNN medium with RPMI-1640 as an overlay[7]. On day 7 p.i., the amastigotes transformed to viable promastigotes which were capable of infecting the macrophages *in vitro*.

Laboratory animals other than non-human primates differ greatly in metabolism and pharmacokinetic behaviour of drugs. The results obtained on these animals have poor extrapolation to human situation. Indian langurs evoke responses parallel to man in respect of drugs and therefore, these are the preferred animals for secondary screening. As with other diseases[8,9] in leishmaniasis too, the langurs probably will allow better translation of experimental results to humans. In human leishmaniasis, the parasites are mainly

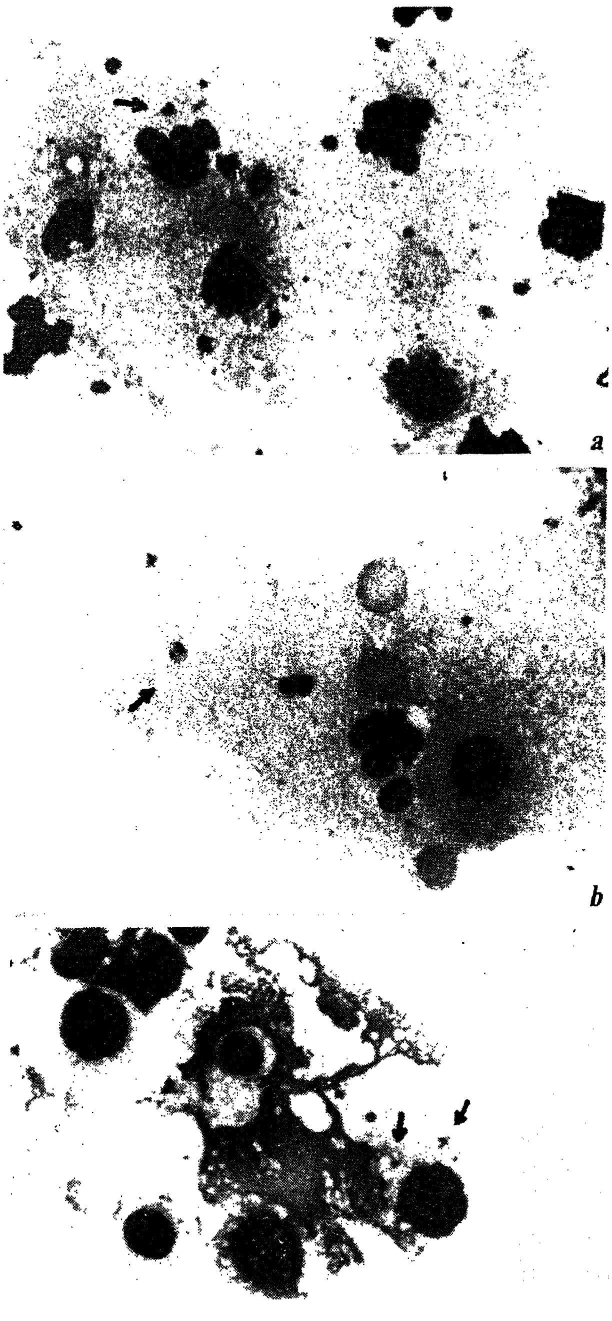

Figure 1. Dab smears showing amastigotes (arrow) of *Leishmania donovani* on day 104 post infection in langur, Giemsa stained, (X 900). *a*, Spleen; *b*, Liver; *c*, Bone marrow.

Table 1. Parasitological and haematological profile of langur monkeys infected with *Leishmania donovani*.

Inoculum: 1 x 10^8 i.v. on forearm

		Haematological parameters												Amastigote number/100 cell nuclei		
				Differential count (%)												
Langur monkey no.	Initial body wt. (kg)	Day of observation p.i.	Total count (no./(Ccm)	P	L	E	M	Hb (%)	RBC (10^6/Cnm)	Hcl (%)	MCV (C)	Platelet count (no./Cmm)	Death occurred on day p.i.	Spleen	Liver	Bone marrow
Control (uninfected)	3–4	0	10,822±2197	51±8	47±8	3–5	1–3	12.33±1.15	5.09±0.41	42.1±2.7	98±5	254,666±67,386	–			
1	3.0	35	16000	40	58	1	1	15.4	5.65	46.4	99	nd	104	6	3	1
		90	16000	15	84	0	1	5.8	2.02	20.3	97	105,000				
2	3.2	35	11600	60	38	2	0	14.5	5.10	49.9	97	nd	108	7	5	2
		90	10000	40	60	0	0	4.4	1.48	15.8	107	125,000				
3	4.0	35	7600	45	54	0	1	13.0	5.01	37.9	75	215,000	110	32	6	9
		110	5200	25	74	0	1	5.4	2.17	15.6	72.0	190,000				
4	4.3	35	7400	35	64	0	1	13.4	5.50	47.7	86	248,000	110	39	7	13
		90	7000	65	34	0	1	6.1	3.00	39.2	99.0	225,000				

concentrated in organs like liver, spleen and bone marrow. In langurs also the level of infection at primary sites simulates the disease process in man—the target host.

The successful transmission of *L. donovani* to Indian langurs and near identical alteration in blood parameters to man are likely to make langurs as the most favourite host for experimentation on visceral leishmaniasis. Attempts are on to assess chemotherapeutic and immunological responses of langurs to *L. donovani* to rank this as the prime host of leishmaniasis.

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Effect of heat shock on the different phases of the mitotic cycle in *Physarum polycephalum*

P. R. Manish Kumar and Vimala R. Nair
Department of Zoology, University of Calicut, Calicut 673 635, India

In view of the heat-labile nature of the mitosis-triggering substance, heat shock (from 24°C to 37°C for 30 min) was given to synchronously mitotic plasmodia of the myxomycete *Physarum polycephalum* at short intervals during the course of one mitotic cycle. The S phase was found to be least sensitive to heat shock, whereas delay increased throughout G_2 till the transition point with respect to heat shock. This point was at about 30 min before metaphase. Heat shock given between transition point and onset of metaphase did not produce any mitotic delay, but resulted in abortive mitosis. Least-squares fitting of the delay curve has been carried out. The delay pattern for late G_2 in our study differs from that of an earlier study and this aspect is discussed.

As part of a programme of study employing perturbers to understand the triggering mechanism of mitosis[1–3], we have now analysed the heat-shock sensitivity of the plasmodium of the myxomycete, *Physarum polycephalum*, during the different phases of a mitotic cycle, that is, from one metaphase to the next. The choice of elevated temperature as a perturber of the mitotic cycle is because of its postulated effect on a heat-labile mitotic-triggering substance in *Physarum*[4], and also on similar substances in certain other organisms[5]. The pattern of the heat-induced, mitotic delay curve which we have obtained for the G_2 phase of this organism, differs from that of an earlier study[6], and hence is reported here.

The plasmodium of *P. polycephalum* is a syncytial system and the large number of nuclei within it are naturally synchronous with respect to mitosis and so this has been a favourite model system[7–9], with those who study cell cycle control mechanisms, particularly the triggering of mitosis[10].

In our laboratory, the Wisconsin strain (M3C) of this organism was grown as microplasmodia, in suspension cultures, on a semi-defined medium (SDM)[11] at 24°C. Although nuclei in each microplasmodium divide in synchrony, the microplasmodia in a culture are random with respect to mitosis. Therefore large, mitotically synchronous surface plasmodia (macroplasmodia) were made by fusion of several microplasmodia (0.4 ml packed suspension) onto Whatman no. 40 filter paper[12]. Such fused plasmodia on filter paper were placed in petri plates supplied with SDM. At regular intervals after fusion, synchronous mitosis was observed in these surface plasmodia. Sister surface plasmodia made from aliquots of pooled microplasmodial suspension are also mitotically synchronous with respect to each other.

The plasmodia of *P. polycephalum* have no G_1 phase and S phase starts soon after the telophase of mitosis and lasts for about a third of the mitotic cycle[13]. The rest of the period is G_2 phase, followed by mitosis. Mitotic timings and the phase of mitosis were determined by observing ethanol-fixed smears under a phase microscope[14].

It would be interesting to see if the small difference in the initial growth temperature of the cultures in these two studies (26°C in Brewer and Rusch[6], compared to the 24°C of our experiments) would lead to such a difference in mitotic delay pattern, the strain of *Physarum* used being the same. The nature of the thermosensitive mitotic substance, which may act through a polymeric structure as proposed by Wright and Tollon[15], indicates such a possibility. Moreover, since various components of the mitotic trigger are so very delicately balanced[16], it is possible that even minor differences of this type could be crucial in perturbation studies dealing with mitotic cycle timings.

By the second mitosis after fusion, each surface plasmodium made as above, had grown large enough (a diameter of approx. 5 cm), so that we were able to cut out five sectors from each of them. Cutting of the plasmodium into sectors of desired size is made easy because of the growth of the plasmodium on filter paper. For a single experiment, covering the approximately 12 h cycle time from the second post-fusion mitosis (PFM) to the third PFM at regular intervals, large number of such sectors were required. After leaving a sector from every plasmodium

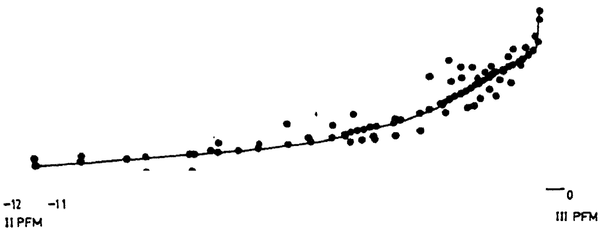

Figure 1. Graph showing mitotic delay induced by heat shock given at different times during the mitotic cycle. Abscissa: time of heat shock (h) in relation to the third PFM of control which is the zero point. The points marked on the graph denote the beginning of the heat shock treatment. Ordinate: delay (h) induced by heat shock in relation to the time of metaphase in the control sectors. M II, Second PFM; M III, Third PFM. Least squares fitted formula:

$$d = 0.048383 + \frac{6.36125}{t} - \frac{5.19437}{t^2} + \frac{1.46561}{t^3}$$

d, delay (h); t, heat shock time (h) prior to metaphase.

as a control at 24°C, the rest of the sectors were heat shocked for 30 min, at desired intervals, by transferring them from their temperature of growth (24°C), to prewarmed (37°C) SDM maintained in an incubator. After this period, the sectors were returned to 24°C. The third PFM (metaphase) in the control sectors served as the reference point for calculating delay in the treated sectors.

The experiment was repeated twice for the whole period of the mitotic cycle, and was repeated thrice more with respect to the G_2 phase alone, as this is the phase where our results differed from that of an earlier study[6]. Since determining the exact delay pattern for G_2 phase was crucial, heat shocks were applied at shorter intervals in two of our experiments covering this period. This was also necessary to locate the transition point (TP) with respect to heat shock.

Data from different experiments are pooled and plotted in Figure 1. Following a convention in mitotic delay studies, metaphase of the control mitosis, which comes after the perturbation schedules, is shown as '0' point on the abscissa and so the rest of the times of this axis are shown with a minus sign. Least-squares fitting of the delay curve has also been carried out.

In agreement with the results of Brewer and Rusch[6], we have observed that the S phase in the mitotic cycle is the least sensitive to heat shock. The mitotic delay due to heat shock was found to increase thereafter throughout G_2, till the TP, at about 30 min before metaphase. Brewer and Rusch[6], on the other hand, observed maximum mitotic delay in plasmodia heat-shocked 2 h prior to metaphase and fall in delay thereafter.

We have also observed that heat shock given between the TP and the onset of metaphase does not delay mitosis. However, such treatments, resulted in an 'abortive' mitosis. This mitosis was abortive in that, no regular spindle was observed. Instead, fibrillar material was seen radiating from the condensed chromatin of the nuclei. Such nuclei revert to interphase, after a few hours, without undergoing mitosis. Others have also observed such abnormal nuclei, following heat shock applied during a crucial period prior to metaphase[6, 15].

Precise identification of the most sensitive phase and the TP with regard to a perturber of the mitotic cycle is required before any further anlaysis of its mode of action with respect to specific target molecules is made. This way the present observations would help in the planning and interpretation of future experiments on heat-sensitive, mitosis triggering proteins.

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Comparative morphogenetic potential of haploid and diploid callus cultures of *Brassica juncea* L.

R. K. Goel, R. K. Jain and J. B. Chowdhury
Department of Genetics, Haryana Agricultural University,
Hisar 125 004, India

Shoot morphogenetic potential of microspore and somatic explant-derived calli of *Brassica juncea* L. on different MS media have been compared. Shoot organogenesis could be induced in anther-derived haploid calli with

comparatively high frequencies (18–58%) and on a wider range of combinations of growth regulators. The highest regeneration frequency was obtained on zeatin + NAA medium. The number of shoots per regenerating callus varied considerably, with two of the anther calli regenerating more than 25 shoots in a single culture. In case of cotyledon and hypocotyl-derived callus cultures, only the calli initiated under light responded positively to shoot regeneration at ca 12% frequency and on only one medium each. Cotyledon calli regenerated on zeatin + NAA medium and hypocotyl calli on BAP + IAA medium. Dark-grown white friable calli failed to yield any shoots.

DEVELOPMENT of plant regeneration protocols is a pre-requisite for the successful application of various *in vitro* techniques. In *Brassica juncea* (Indian mustard, $2n=36$, genome formula—AABB), a major oilseed crop of India, while such protocols have been developed for various explant tissues[1–7], are a few for anther cultures[8] and somatic callus cultures in this crop species. Especially in the latter case, plant regeneration frequencies have been very low. This communication describes culture conditions for plant regeneration and differential shoot regeneration response in anther-derived haploid and somatic explant (cotyledon and hypocotyl)-derived calli of *B. juncea* cv. Prakash.

Anther and somatic explant cultures of *B. juncea* L. cv. Prakash were raised according to the protocols described earlier[3, 9]. Ploidy level of the anther-derived calli was assessed by pretreating the cells with colchicine for 3 h, fixing in Carnoy's II and squashing and staining in acetocarmine. Anther-derived calli that had haploid cells were used subsequently for regeneration studies. While anther calli were raised and maintained under dark before regeneration experiments, somatic explant calli were initiated both under light and dark. For shoot regeneration, about 2-months-old microspore and somatic explant-raised calli were cut into small pieces of approximately 50 mg weight each and transferred onto media with several different combinations of cytokinins and auxins (Table 1) in petri plates. Five calli were cultured per petri plate and 12 petri plates were used for each media treatment. The cultures were scored for shoot regenerants after 30 days. All the cultures were kept under 16 h photoperiod fluorescent light of 4000 lux intensity. All the media contained MS[10] basal medium, 3% w/v sucrose and 0.8% w/v agar–agar and adjusted to pH 5.8 before autoclaving.

The shoot regeneration data comparing the morphogenetic potential of the microspore- and somatic explant-derived calli on different media are presented in Table 1. Within 10 days of culture, callus started differentiating certain nodular structures, which subsequently formed shoot buds. In another week, the buds gave rise to shoots. However, such a response varied considerably with the callus source, photoperiod condition during the callus initiation and maintenance and hormonal constitution of the medium (Table 1). Anther-derived haploid calli responded to shoot regeneration with comparatively high frequencies (18–58%) and on a wider range of combinations of growth regulators. Highest regeneration frequency (58%) was obtained on high zeatin α-naphthaleneacetic acid (NAA) concentration ratio in the medium. Shoot regeneration declined to 19% when NAA was substituted with indoleacetic acid (IAA) in this medium. Kinetin along with a low NAA/IAA concentration was also supportive of shoot regeneration. Shoot regeneration increased further, when kinetin concentration in the medium was increased to 10 mg l^{-1}. To put together, among cytokinins zeatin was most potent followed by kinetin and 6-benzyl aminopurine (BAP) and among auxins NAA and than IAA, in causing shoot regeneration. The number of shoots per regenerating callus varied considerably (Table 1), maximum being on zeatin + NAA medium. Two of the anther calli showed exceptionally pronouned shoot organogenesis and could regenerate more than 25 visible shoots within four weeks on zeatin + NAA medium.

Table 1. Shoot organogenesis in anther-, cotyledon- and hypocotyl-derived calli of *Brassica juncea* cv. Prakash.

Cytokinins (mg l^{-1})		Auxins* (mg l^{-1})		% Shoot regeneration: Microspore callus	Cotyledon callus*	Hypocotyl callus*
BAP	2.0	IAA	0.2	0	0	12.0(1–5)
	2.0	NAA	0.2	25.0 (1–5)	0	0
Kinetin	2.0	IAA	0.2	27.5 (1–3)	0	0
	3.0		0.5	—	0	0
	10.0		0.5	33.3 (1–5)	—	—
	2.0	NAA	0.2	25.0 (1–5)	0	0
	10.0		0.5	41.8 (1–10)	0	0
Zeatin	1.0	IAA	0.1	18.8 (1–3)	0	0
	1.0	NAA	0.1	58.3 (>5)	12.5 (1–5)	0
Average**				28.7^{b}	1.56^{a}	1.50^{a}

Values in parentheses indicate range of the number of shoots per regenerating callus.

*Calli initiated under 16 h photoperiod.

**Averages with different alphabets are significantly ($P < 0.001$) different from each other, Tukey Multiple Range Test.

In cotyledon- and hypocotyl-derived callus culture, only the green compact calli, the ones initiated under light conditions responded to shoot regeneration and that too on only one medium each (Table 1). Cotyledon calli regenerated on zeatin + NAA medium and the ones of hypocotyl origin on BAP + IAA medium. Dark grown white coloured friable calli failed to yield any shoots.

It is interesting to note that even the fresh calli derived from the somatic explants, especially the cotyledonary explants which have been shown to be highly morphogenic[3], showed poor shoot regeneration. Murata and Orton[5], while conducting regeneration studies from various somatic explants in different *Brassica* species, also observed a similar drastic decrease in the shoot morphogenic potential in freshly initiated explant callus cultures. The reasons for this loss of competance is not clear. On the other hand, microspore cultures had comparatively much higher shoot morphogenic potential, and on a wider range of media. Increased regeneration capacities of such cultures could be due to hemi- or homo-zygous condition of the genes inducing and/or promoting the shoot regeneration. If, it is true, it should be possible to establish genotypes with higher morphogenetic potential. The study nevertheless showed that microspore-derived cultures by virtue of their higher regeneration competance should be preferred over somatic explant cultures for *in vitro* applications such as *in vitro* screening for desirable mutants.

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5 September 1989

INSA MEDAL FOR YOUNG SCIENTISTS—1991

Instituted by the Indian National Science Academy in 1974 the Medal is awarded annually in recognition of outstanding work of scientists below the age of 32 (as reckoned on 31st December preceding the year of award). Only those born on or after 1 January 1959 are eligible for consideration in 1991. The work done in India by the nominee will be taken into consideration for the award.

The awardee is presented a medal and a cash award of Rs. 10,000/-. In addition, the recipient is considered for a research grant by the Academy not exceeding Rs. 30,000/- per year, including stipend for a JRF for a period of three years for continuing research work, provided the research proposal is considered worthy of such support. Preferential consideration may be given under partial travel grant scheme for attending international conferences.

Nominations for the awards for 1991 may be made by Fellows of the Academy, as also by the established scientific societies of all India character, university faculties and departments, or the research institutions.

The last date for the receipt of nominations in the Academy is 15 November 1990.

Nomination Proforma can be obtained from the Indian National Science Academy, Bahadur Shah Zafar Marg, New Delhi 110 002 by sending a self-addressed envelope of 28 x 12 cm size.

Setting up good models of behaviour

Dynamic Programming in Behavioral Ecology. M. Mangal and C. Clark. Princeton University Press, Princeton, NJ, USA, 1988.

Dynamic programming is an optimization technique first developed in 1957 by Richard Bellman. It has been successfully applied to many problems in engineering and management. The present book is an exposition of how it may be used in modelling animal behaviour. Because animals encounter a random environment, the model has to be probabilistic. In particular, a decision to be taken at a given point of time is assumed to be Markovian, i.e. based on the state of affairs in the immediately preceding period. A discrete framework is used in the sense that time is counted in days, or hours, or other convenient unit. The variety of applications discussed in the book, both in terms of species and types of behaviour, is fascinating. Starting with group hunting by lions, we are carried, through parental care in birds, to diurnal migration of fish and zooplankton. In each illustration, a particular behaviour of an organism is described and the current explanation of that behaviour available in the literature is presented. Finally the dynamic stochastic programming approach is worked out, which often yields a different/better explanation of the observed behaviour. It is of course assumed that behaviour has been so shaped by natural selection that it yields maximum benefit to the organism. While the standard definition of benefit is inclusive fitness, different surrogates have been used in different examples for operational convenience. The surrogate measure may be probability of survival, total energy reserve, or number of progeny at the end of a given period. In some examples the relevant period is 'natural' (e.g., in the case of nesting birds, from the time of egg-laying to the time when chicks become independent), but not in all. The optimization is dynamic in so far as there is feedback and updating of information at the end of each unit of time. In this the present approach differs from, say, optimal foraging theory (see Stephens, D. W. and Krebs, J. R., *Foraging Theory*, Princeton Univeristy Press, Princeton, 1986). Thus the marginal value theorem in the static formulation tells us that to get optimal result a forager should move from one patch to another as soon as the patch is depleted to a certain extent. But it does not take into account the state of hunger of the forager, which may have changed by virtue of its having spent some time in that patch. The dynamic-modelling approach gives the best decision as a function of the state of hunger as well as the remaining time on hand. Another distinguishing feature of the dynamic approach is that, given the values of all relevant parameters, the method yields precise numerical predictions and not just qualitative ones. This of course necessitates considerable computing, and for any significant application of the method, access to a PC is essential.

Do the answers arrived at using the dynamic-programming approach differ significantly from those based on a static approach? Indeed, and often enough to merit attention. One case that I found rather convincing is the following. An insect has to search for hosts of various types and to lay one or more eggs every time a host is encountered until the stock of eggs is exhausted or time runs out. As the number of eggs laid on a host increases, the probability that an emerging larva will reach maturity decreases, say due to competition. Then one can obtain the number of eggs to be laid on a host so as to maximize the expected number of mature offspring. This is the static optimum. Field observations show that actual number of eggs laid varies considerably from this optimum and is always on the lower side. The dynamic approach brings to our attention the fact that, early in the game, as the insect sets out in search of hosts, it is more profitable to lay one or a small number of eggs on a host since there exists a fair probability of finding many more hosts and providing a very favourable environment for each egg. As time runs out it is better to dump many eggs on each host. But it is never good to exceed the static optimum mentioned above, for the extra eggs laid cause excessive competition among the larvae, which may result in mortality among not only the larvae from the extra eggs but others that might have survived otherwise.

The two authors are excellent classroom communicators. They have adopted the same pedagogical style in writing this book, which is meant for biologists and not mathematical theoreticians. The result is a do-it-yourself book. If one has enough motivation and patience to follow the instructions given by the authors step by step, it should not be difficult to get the hang of their method. And this is where the rub is. Too many Indian biologists are divorced from mathematics (and some even from the hypothetico-deductive method). Some find it convenient to stick to descriptive natural history of behaviour rather than raise the question 'why'. There is the ever-present temptation to defend one's elementary work as 'benchmark' (first ever for that species/for that region/for that season). Would such a person want to work through this book? My own recommendation is that ecologists with any background should read this book, perhaps skipping all equations and such other details, to see if the findings are interesting enough to justify further investment of effort.

Statisticians will find this book interesting for another reason. It is well known that, whether it is the lifetime of a butterfly or an electric bulb, the same techniques of survival analysis are used. This book will show that it is also true of dynamic programming, hitherto taught only in courses of operations research and industrial statistics.

Ecologists inclined to modelling may feel deterred by the requirement of data (values of various parameters involved). My impression is that (a) formulation of the problem in the dynamic-programming framework can itself enhance understanding to some extent and (b) with only partial availability of data, the model can be used to indicate the field measurement more likely to be useful in prediction.

A. P. GORE

Dept of Statistics
University of Poona
Pune 411 007

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INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Hari Om Ashram Trust Awards for the year 1990

Nominations are invited for the Hari Om Ashram Trust Awards for the year 1990. Three awards of the value of Rs.10,000/- each in cash or kind or both are given every year for outstanding original research, fundamental or applied, work done in India, including inventions, discoveries, etc. leading to results of practical value in any field or subject within the purview of research in agricultural sciences, forest farming and social forestry and animal sciences (including fisheries).

All scientists engaged in research in the fields of agriculture, forest farming and social forestry, animal husbandry and allied sciences in India shall be eligible for the awards. The results of research achieved/contributions made during the five years preceding the year of the award shall only be considered for the awards. In the case of claims-based on evolution of new varieties/strains, the final trails should have been completed within five years preceding the year of award.

Nominations can be made by amongst others vice-chancellors of agricultural universities or other universities having faculty of agricultural or biological sciences, directors of research institutes, including principals of agricultural and veterinary colleges, presidents of scientific societies, academies and heads of the principal scientific establishments in the country.

Nominations for the awards should be supported by a statement of work, achievement accomplished or performed by the candidate who is being nominated and a reasoned justifications or other supporting data.

The last date for receiving nominations for the awards is 20th September, 1990. The last date for candidates in the Andaman and Nicobar Islands, Lakshdweep, States/Union Territory in the North Eastern Region, Ladakh Division of J&K States and Sikkim is 5th October, 1990. Five copies of the nominations on the prescribed proformae for the award should be sent in a sealed cover marked 'Confidential' to Shri Satinder Singh, Deputy Secretary (A), Indian Council of Agricultural Research, Krishi Bhavan, New Delhi 110 001. The copy of the proforma can be obtained from him by sending a self-addressed envelope of the size of 27 cm x 12 cm. Applications/nominations received without five sets of reprints of publications are liable to be rejected at the scrutiny stage.

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Jawaharlal Nehru Awards for Outstanding Post-graduate Research in Agriculture—1990

The Indian Council of Agricultural Research invites applications from post-graduate students who have obtained their Ph D degrees during the year 1989 in India in the fields of agriculture/animal sciences (including fisheries) and home science for the Jawaharlal Nehru Award for Outstanding Post-graduate Research in Agriculture—1990. There will be ten prizes of Rs 5,000/- each for outstanding research work of the following nature:

(i) which may have bearing on finding a solution to any important national problem in the field of agriculture/animal sciences, and/or

(ii) which is likely to have an impact on increasing the production or improving the quality of any important crop for human nutrition or animal productivity or increasing the technological efficiency of any process of economic importance connected with agriculture.

Candidates shall be required to submit the following documents through the Head of the Institute from where the thesis has been obtained:

A copy of the thesis submitted by them for the award of the doctoral degree

A certificate from the guide of the candidate for Ph D degree stating the extent to which the work is the candidate's own contribution

Six copies of the synopsis indicating precisely and in concise terms the work done by the candidate

Six copies of the bio-data with complete address for correspondence with telegraphic address if possible.

The certificate awarded to the candidate for Ph D degree may also be sent. There is no prescribed proforma for applying for this award. Each candidate will be judged on the basis of the originality and the applied value of the investigations as revealed in the thesis submitted by him. In all matters relating to the award the decision of the Council shall be final and no correspondence on this account will be entertained.

Applications, with complete documents as mentioned above, addressed to Shri Satinder Singh, Deputy Secretary (A), Indian Council of Agricultural Research, Krishi Bhavan, New Delhi 110 001 should be sent so as to reach on or before 20 September 1990. The last date for candidates in the Andaman and Nicobar Islands, Lakshadweep, States/Union Territory in the North Eastern Region, Ladakh Division of J&K State and Sikkim is 5 October 1990. The award-winning thesis will be retained by the Council for record. In case the application is not accompanied by a copy of thesis and the required number of synopsis and bio-data, the application is liable to be rejected at the screening stage.

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Dr Rajendra Prasad Award for the Best Original Standard Works in Hindi on Agriculture including Animal Sciences and Fisheries—1990

Applications are invited for Dr Rajendra Prasad Award for the year 1990 for standard original books/manuscripts in Hindi on agriculture, including animal sciences and fisheries published/written during one year preceding the year of the award. Under this prize, three prizes of the value of Rs.10,000/-, Rs. 5,000/-, Rs. 3,000/- as first, second and third prizes respectively in cash or kind or both will be given each calendar year. Books written by more than one author can also be considered. Five copies of the books/manuscripts for the award may be sent in a sealed cover marked *'Confidential'* to Shri Satinder Singh, Deputy Secretary (A), Indian Council of Agricultural Research, Krishi Bhavan, New Delhi 110 001 latest by 20 September 1990 in a prescribed form obtainable from him. The last date for candidates in the Andaman and Nicobar Islands, Lakshdweep, States/Union Territory in the North Eastern Region, Ladakh Division of J&K State and Sikkim is 5 October 1990.

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Supplement to Current Science, 25 June 1990, vol. 59, no. 12

ASTRONOMY PROFILE FOR THE NINETIES
THE INDIAN SCENARIO

Extracted* and adapted
from the report

ASTRONOMY AND ASTROPHYSICS FACILITIES PROPOSED FOR THE EIGHTH FIVE-YEAR PLAN 1990–95

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*This is an extract by Prof. B. V. Sreekantan, chairman of the National Meeting on Astronomy Facilities, from the report of the meeting. The list of participants of this meeting is given in the Annexure.

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1 PREAMBLE

About sixty scientists – astronomers, physicists and engineers – participated in a meeting held at the Indian Institute of Astrophysics, Bangalore, on 24 and 25 August 1989 to discuss the Indian profile for astronomical research in the '90s, and the major astronomical instrumentation that needs to be provided for in the future, taking into consideration the optimal utilization of the existing facilities and their upgradation. The meeting had been organized by the Department of Science and Tehnology (DST) of the Government of India at the instance of the Planning Commission and in the context of the projection of the financial outlays for the Eighth Plan period 1990–95. A large number of young scientists from various institutions participated in the discussions. The meetings were also attended by representatives from DST, the University Grants Commission (UGC) and the Planning Commission.

The well-structured series of plenary sessions, parallel sessions and expert group discussions provided plenty of opportunities for not only formal presentations of the various Eighth Plan proposals of the different institutions in the area of astronomy and astrophysics, but also for free and in-depth discussions, which enabled the formulation of strategies, priorities and phasings and modalities of execution of the projects. A very important aspect that received special attention at the meetings was the question of development of trained manpower for the different projects and the involvement of the universities in this regard.

The meeting began with a brief presentation on the historical trend of astronomical research. It was emphasised that astronomy, even though the oldest of all sciences, has continued to flourish and open up new vistas and gateways to knowledge of the fascinating universe, its constituents, its forces, its origin and evolution. A major factor responsible for the unabating activity in this field is the ever-increasing role of different fields of technology—electronics, communications, computers, and space technology—which have thrown open all bands of the electromagnetic spectrum and all kinds of particulate radiations for observation and analysis. It is no exaggeration to say that the scope and opportunities in this field for the future are as varied and as vast as the universe itself. However, as highlighted by Martin Harwit in his book *Cosmic Discovery*, some very interesting and instructive aspects emerge from a study of the patterns of the most significant discoveries in this field. These are: (i) nearly 50% of the discoveries since antiquity were made by those who were not professionally trained as astronomers; this percentage has increased to 70% in the last four decades; (ii) a large fraction of the discoveries were serendipitous; (iii) the use of new instruments and new techniques has always been rewarded by major discoveries; (iv) hardly any of the astronomical discoveries were predicted by theoretical considerations, an exception being the 21 cm line. Figure 1, taken from Harwit's book, gives an idea of the chronology of the discoveries and the rapid pace of discoveries in recent decades. The discovery of neutrinos from SN 1987a has been added to the figure given by Harwit.

What these features tell us in the most clear terms is that for success in this field there should be (i) increased observational opportunities, (ii) larger number of scientists making observations, and (iii) scope for development and deployment of new types of instruments and techniques.

Not only has the scope of astronomy been considerably enhanced by the range of observations, the nature of investigation itself has undergone radical changes. Simultaneous and sequential observations in multispectral bands on the same celestial objects with telescopes all over the world have became a common feature to extract more information on the peculiar environments of these objects. Observations on bursts, flares and transients have brought a fresh focus on binary systems exchanging matter, with one of the components being a collapsed compact object like a neutron star or black hole. There is increasing interaction and collaboration between astronomers, cosmologists, astrophysicists and high energy particle physicists with the realization that the first moments of the universe could have been the highest energy accelerator laboratory producing all kinds of elementary particles, some of which may still be around in the universe in some form or the other. Large-scale experimental searches have been organized to track down such remnants. Technology has brought within the realm of feasibility neutrino astronomy, gravitational wave astronomy, exotic particle astronomy, and so on.

In the context of the global effort what is the status of Indian effort in these diverse fields of astronomy and astrophysics? How do we cultivate, nurture and grow the instrumentation culture so vital to this field? How do we draw young scientists from different disciplines and more university students into this challenging, exciting field? What should be our strategies and priorities?

These were the specific issues that were deliberated upon at the Bangalore meeting in August 1989. In the first part of the report the global scenario of astronomy and astrophysics and the current status in India are briefly summarized. In the second part, brief comments on the various proposals discussed at the meeting, reflecting the general reactions, are given, followed by a series of detailed recommendations and suggestions regarding modalities of implementation and financial outlays during the Eighth Plan.

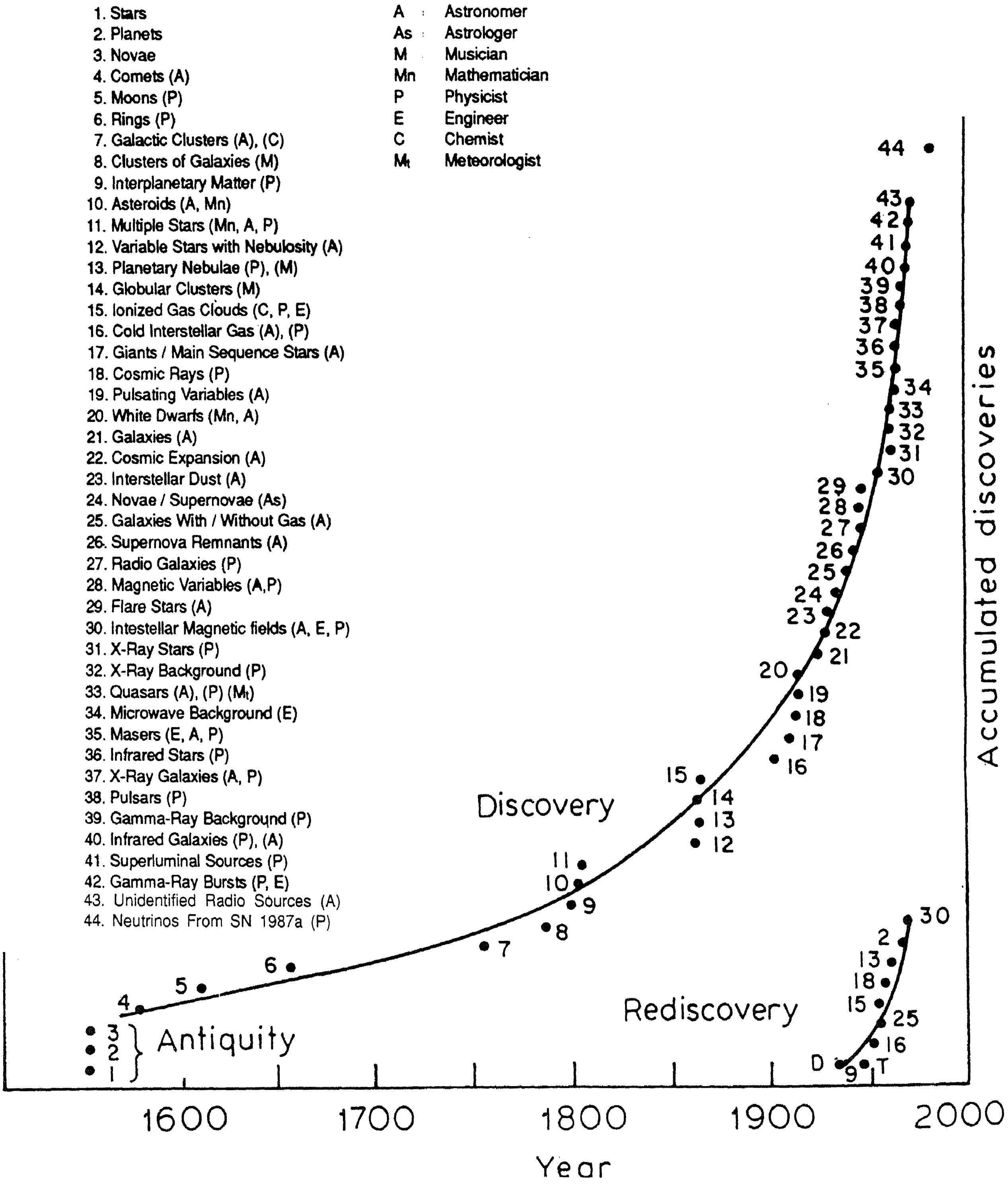

Figure 1. Chronology of discoveries in astronomy and astrophysics. [From *Cosmic Discovery* by Martin Harwit]

2 ASTRONOMY IN PERSPECTIVE

2.1 ASTRONOMY TODAY —THE GLOBAL SCENE

Beginning with the naked-eye observations thousands of years ago, with the progressive deployment of larger and larger telescopes from the time of Galileo, and the use of a variety of focal plane instruments—photographic plates, spectroscopes, photomultipliers, CCDs, etc.—in successive periods, the field of optical astronomy has provided a wealth of information on planets, comets, stars, galaxies, clusters of galaxies, interstellar and intergalactic media, stellar explosions and a variety of celestial phenomena, and on the numbers, distances, masses and temperatures of these objects, the hierarchy of structures, the universality of the chemical abundances and the universality of the laws of nature, and, most important, the thoroughly unexpected universal expansion of the universe—each galaxy moving away from its neighbour, the greater the separation, the greater the velocity of recession.

The vast amount of information on the universe obtained through optical observations has been further enhanced and complemented from what has been obtained in the other bands of the electromagnetic spectrum. Since the early '30s, particularly since the '50s, radio astronomy has opened up new vistas on the universe and its constituents—the neutral hydrogen clouds, the quasars, the high-red-shift objects, the pulsars, the neutron stars, the universal 3° microwave radiation, complex organic molecules in interstellar clouds, radio stars, radio galaxies even at the edge of the universe.

Observations in the infrared, both from ground and from high-altitude balloons and satellites, have brought focus on relatively cold regions in the universe where star formation is proceeding. Newer types of environments and high-energy physical processes that characterize these environments have been brought to light by observations in the ultraviolet, X-ray and gamma-ray regions that became possible with the advent of the space era of rockets and satellites. For the first time the emission of neutrinos in stellar explosions has been recorded in deep underground laboratories. While solar radio and optical astronomies have progressed considerably, the observations on the solar neutrinos have created a big puzzle.

All this information has no doubt led to considerable progress in our attempts to understand some of the basic questions—the origin and evolution of the universe, the basic constituents, and the basic forces that have operated at various stages of evolution and continue to operate. However, new questions and new puzzles have also arisen. A lot more information in the different bands has become essential. Newer techniques and newer methods of analysis and data processing hold the promise towards a solution of the most challenging problems. The Hubble Space Telescope may prove to be yet another turning point in the long and dynamic history of astronomy, opening up many more issues to be settled in the coming generations. Astronomers, astrophysicists and high energy particle physicists are coming together to unravel the events in the first moments of the universe, beginning with the big bang. There is no doubt that astronomy will remain a frontier area for decades to come, and will become increasingly multidisciplinary in character.

2.2 ASTRONOMY AND ASTROPHYSICS IN INDIA

A detailed and lucid account of the historical development of astronomy in India and the exact status of the different fields, as it prevailed in 1982, is available in the report prepared by Prof. R. R. Daniel and published by the Indian Space Research Organisation (ISRO-ADCOS-SR-10-82). There is also an Indian National Science Academy report (1984) on 'Thrust Areas in Astronomy and Astrophysics' by Dr J. C. Bhattacharyya and Dr V. R. Venugopal.

These reports show that the astronomical activity in India has quite a wide base and covers practically all branches of astronomy—optical, radio, infrared, X-ray, gamma-ray and cosmic rays. In some of these areas, research is being carried out at the international level of competition with instruments that compare favourably with the best in the world. However, it has to be emphasized that, considering the size of the country and the number of science graduates that come out from the universities, the quantum of astronomical research is still small. Many more facilities have to be created. Compared to many other disciplines in basic science, the returns in terms of scientific output from a particular quantum of investment is maximum in the case of astronomy. This aspect is very clearly brought out by an analysis of the returns from the Ooty Radio Telescope (ORT). Built at a cost of less than Rs 1.5 crores in the period 1965–69, this unique facility has generated in the past 20 years over 350 research papers published in international journals and 20 PhD theses and very significant original results on angular sizes of the most distant radio sources. At a very small cost this telescope has now been extended into the Ooty Synthesis Radio Telescope, enhancing its capabilities further.

The Vainu Bappu Optical Telescope (VBT) of the Indian Institute of Astrophysics (IIA) and the 10-metre millimetre wave telescope of the Raman Research Institute (RRI) are further examples of the construction at very low cost of world-class instruments by a few motivated individuals. This tradition and philosophy has to be continued in our future endeavours as well. Astronomy, as already emphasized, has become a multidisciplinary field which opens up opportunities for those who specialize in widely different branches of pure and applied science.

In the area of theoretical astrophysics investigations are going on in several aspects of solar physics, solar oscillation, star formation, supernova explosions, neutron star phenomena, pulsars, black holes, the early universe and cosmology. There is increasing interaction between observational astronomers and theoretical astrophysicists.

2.3 FUTURE APPROACH FOR PURSUIT OF ASTRONOMY IN INDIA

As a result of several initiatives taken by the astronomy community during the Seventh and earlier Five-Year Plans through their respective institutions/agencies, considerable amount of infrastructure in terms of facilities and major systems has been set up at different places in the country. In view of the rapid advances in astronomy and exciting new problems, the astronomy community has been considering taking up new and challenging areas of research during the Eighth Five-Year Plan and has made individual proposals to the respective organizations as well as to the Planning Commission. for setting up major national facilities. In view of this, the Planning Commission had desired that DST organize a national meeting where all such proposals for setting up major facilities during the Eighth Plan are discussed in the context of infrastructure already set up during the earlier Plans and its maximal utilization, and at the same time, take up, in an integrated manner, new programmes using national facilities which could be set up during the Eighth Plan. The number of proposals received was very large and it was necessary to have some kind of prioritization and an understanding reached as to how major facilities which may be set up in the Eighth Plan could be effectively used by the astronomy community as truly national facilities.

In order to arrive at this process of prioritization, DST, in consultation with the members of the Astronomical Society of India and various organizations and agencies, arranged a national meeting on 24 and 25 August 1989 in Bangalore. The meeting was organized after an intensive preparation which involved not only discussions amongst the astronomy community but also preparation of about 24 proposals carefully drawn out in a standard format so as to highlight the importance of the area proposed to be pursued using the national facilities, also to evaluate the existing strength, capabilities, as well as organizational and other constraints, which would enable the community to take a decision regarding the priority to be given to various proposals.

A major element in this exercise involved an integrated approach which came out as a result of DST/UGC interaction and where the requirements of the university astronomy community were looked at in an integrated and coordinated manner and presented at the national meeting by the representatives nominated by UGC.

In some cases there were some doubts expressed as to whether the proposals discussed at the Bangalore meeting have all to be considered as national facilities or not, and, to that extent, whether the investments which were expected to be made should be integrated into overall requirements of the national facilities or would these activities be subsumed under the individual institutional budgets. This aspect has, to a certain extent, been resolved by considering only major national facilities which would be available to the astronomy community as a whole and for which resources are going to be projected in this document. The normal programmes of the individual institutions are expected to be taken care of in the normal plan budgets of the respective institutions.

3 PROPOSALS AND COMMENTS

3.1 THE PROPOSALS

3.1.1 National projects

National projects started in the earlier plans which will be completed during the Eighth Plan.

(i) The Vainu Bappu 2.34-metre Optical Telescope (VBT)
(ii) The Giant Metre-wave Radio Telescope (GMRT)

3.1.2 New facilities and new programmes

(i) Development of astronomy in the universities-manpower development
(ii) New national projects
(a) Very Large Optical Telescope
(b) Solar Vacuum Telescope
(c) One-metre class telescope for special observations
(iii) (a) Astronomical instrumentation centres
(b) Astronomical data centre
(iv) Development of new technologies, new fields of astronomy

3.1.3 Upgradation of existing facilities

Upgradation and modernisation of the existing facilities in the different astronomical centres

3.1.4 The Positional Astronomy Centre

3.2 JUSTIFICATIONS / COMMENTS ON THE PROPOSALS

3.2.1 The Vainu Bappu Telescope

The 2.34-metre optical telescope was designed and indigenously built by IIA during the period 1974–85 and was installed at Kavalur towards the end of 1985. The telescope and the Kavalur Observatory were very appropriately named 'The Vainu Bappu Telescope' and 'The Vainu Bappu Observatory' in honour of the internationally well known pioneer astronomer of India Dr Vainu Bappu, who died prematurely in 1982. The 2.34-metre telescope was his vision and his creation.

Till recently observations with the telescope were being carried out only at the prime focus. The cassegramin focus is expected to become operational over the next few months.

While the VBT is equipped with a few specialized accessories, such as a VAX 11/780 computer, a Perkin-Elmer data digitizing unit, and a CCD camera system with a PC, still a considerable amount of augmentation has to be done with regard to focal-plane instrumentation—fibre-linked Coude spectrograph for high-resolution spectroscopy, spectropolarimeters and speckle camera. With the availability of high-resolution spectrograph it will become feasible to study a variety of astronomical problems of current intereststellar evolution, elemental abundances, isotopic ratios, stellar winds, stellar magnetic fields, globular clusters, galactic halo, kinematics of galaxies and galactic nuclei. A major interest in the VBT is to go to very faint objects and study structure and evolution of galaxies and their nuclei. The VBT will also be extensively used for identification of special objects picked up with the Ooty radio telescope, as well as with the GMRT when it become operational.

3.2.2 The Giant Metre-wave Telescope

The Giant Metre-wave Telescope project of the Tata Institute of Fundamental Research (TIFR) was approved as a high-priority project in the Seventh Plan. It has made good progress. GMRT will consist of 34 fully steerable parabolic dishes each of diameter 45 m. Sixteen of them will be placed in a central compact area of 1 km^2 and the other 18 will be placed along the 3 arms of a 'Y' and extended up to a maximum distance of 14 km from the centre. GMRT will be the largest facility in the world for astronomical research in the metre and decametre wave bands (38 to 1420 MHz). Such a telescope is nearly impossible to operate with success in advanced countries because of the very high level of man-made radio disturbances. Fortunately measurements revealed that this disturbance is still low in India, particularly in the location (Narayangaon) chosen specially from this point of view. Even in India this situation may not continue beyond a few decades from now. It is therefore an opportune time that this telescope be built and operated for a decade or two. While the first 45 m dish will be installed by July 1990, subsequently one antenna will be commissioned every month. The full array becomes operational by March 1993. The individual dishes being themselves very-large, very meaningful astronomical observation will start even with the commissioning of a few dishes, which will be by mid-1991. It is planned that by the end of 1992—the ICSU International Space Year—GMRT will be almost fully operational. That will be a major contribution to space research by a Third World country.

GMRT will tackle many outstanding astronomical problems. The most exciting among these is the distinct possibility of observing the high-red-shifted 21 cm line profile emanating from primordial clouds of neutral hydrogen. The expected frequency range is 130 to 350 MHz, corresponding to red shift z of 3 to 10. If this is achieved it would perhaps be the most outstanding discovery of the last decade of this century. The telescope has the potential of discovering several thousand pulsars and also increase by an order of magnitude the statistics on binary and millisecond pulsars. RRI has proposed building a special pulsar detection machine to be operated with GMRT.

An enormous amount of new information will become available on many aspects of normal galaxies, radio galaxies, quasars, clusters, steep spectrum radio sources, etc. GMRT will also be a powerful addition to the worldwide network of radio telescopes for very-long-baseline interferometry (VLBI), and also with space radio telescopes planned to be launched by several countries, including India.

GMRT is designed and constructed as a world-class telescope, with many novel features incorporated for the first time. It will be equipped with the most up-to-date electronics instruments and parallel-processing computer systems. The academic and R&D headquarters of GMRT has been established in a specially built complex in the Poona University area, while the array itself will be at Narayangaon, 80 km from Pune. The most challenging requirement for the full utilization of this wonderful facility is the mobilization of high-quality young astronomers/ physicists in sufficient number.

3.2.3 Astronomy in the universities—Manpower development for the '90s

Traditionally, in most of the advanced countries, astronomy and astrophysics developed in the university departments, which were also the seat for manpower development. Though, because of the extreme sophistication and high technology inputs required, even in other countries the activities in this field have shifted to specialized centres and institutes, the teaching and training of manpower continues in the universities and in the research departments associated with universities. Eminent astronomers continue to be on the faculties of the universities.

In India the situation is completely different. Out of the 120 or so universities only two have a department of astronomy, and in only a dozen or so universities there is just a special paper in astronomy in the degree courses, at the level of BSc or MSc or MPhil. The student community in India has practically no exposure and training in this most fascinating interdisciplinary field, which is contributing to the most staggering discoveries in the frontiers of science, drawing upon the most sophisticated technological developments in space sciences, electronics and communications.

The only two universities that have astronomy departments are the Osmania University at Hyderabad and the Punjabi University at Patiala. The Osmania University Department of Astronomy has courses leading upto MSc and MPhil in astronomy and has over the years produced about 15 PhD's in astronomy. The faculty and students use the 48-inch Japal Rangapur Telescope for their research. The Rangapur Observatory is part of the Department of Astronomy. The Punjabi University at Patiala has a 24-inch telescope, trains students in astronomy and space sciences, and has programmes in the development of astronomical instruments to a limited extent.

The 48-inch Japal Rangapur Telescope is also used by other research institutions like TIFR, the Indian Space Research Organization (ISRO) and the Physical Research Laboratory (PRL) for observations in the optical and infrared. The performance of the imported telescope installed in 1968 has deteriorated over the years and considerable repairs and upgradation are necessary. A team of engineers from the SHAR Centre of ISRO have gone into the details of the working of this telescope and have recommended the steps to be taken for renovation and modernization. The proposal has been submitted to UGC. It is recommended that UGC take urgent steps in this regard.

Surprisingly, in the eastern part of the country there exist no major astronomical facilities at all even though one of the most famous astrophysicists of the world, Megnad Saha, hailed from this part of India. In a joint proposal submitted by the Saha Institute of Nuclear Physics, which is part of Calcutta University, and the University of Burdwan and also by the Institute of Radio Physics, Calcutta University, the idea of creating centralized facilities in optical and radio astronomy in this part of the country has been mooted. It is envisaged that such centralized facilities would serve all the universities in the eastern sector—Burdwan, Calcutta, Jadavpur, Kalyani, North Bengal, Viswa Bharati and Gauhati. The proposal is to set up a 24-inch optical telescope with all the accessories and also a radio astronomy centre that will have close links with GMRT and develop a variety of projects in the metre and millimetre wave bands.

The other university that has come up with specific proposals for undertaking development in the field of radio astronomy is the Madurai Kamaraj University, which will have close links with the Radio Astronomy Centre at Ooty. There is also a proposal by the University of Delhi for setting up an array for radio-astronomical observations. Besides these, a survey by Prof. K. D. Abhyankar shows tht several of the universities would initiate training in astronomy if certain minimum facilities like a 14-inch telescope with accessories are made available to them. These universities are Aligarh, Bangalore, (and the Indian Institute of Science, IISc), Bhubaneswar, Gorakhpur, Lucknow, Raipur, Srinagar, Shantiniketan and Gauhati. The Gujarat University at Ahmedabad has started a department of space sciences.

A welcome and very desirable development has been the setting up of the Inter-University Centre for Astronomy and Astrophysics (IUCAA) by UGC. This has started functioning at Poona University, where the headquarters of the GMRT project is also located.

With these developments, it looks quite promising that astronomy programme may take off in the universities and over a period of time contribute effectively towards development of manpower. What is essential however is that adequate funds and appropriate management and organization structures are made available in the university system—earmarked specifically for the development of astronomy programmes—during the Eighth Plan period.

3.2.4 Large Optical Telescope

The world's large telescopes like the 200-inch on Mount Palomar, the four-metre class telescopes in the USA, Chile (CTIO, ESO) and Spain (La Palma), and the Anglo-Australian Telescope in Australia are extending the range of observations to fainter and fainter objects—stars, galaxies, QSOs, etc.—to magnitude fainter than 22. The search is on, and has to be pursued, for primeval galaxies, stellar populations in the external galaxies, interstellar medium in such galaxies, globular clusters, faint quasars and early chemical history of the galaxy. These contain information on the creation and evolution of the universe. The very large telescopes that are envisaged or under execution are:

(i) the 16-metre very large telescope (VLT), by the European Southern Observatory
(ii) the 10-metre Keck Telescope, of the University of California
(iii) the 7.25-metre range telescopes, by the UK, Germany, Italy and Japan.

There is no reason why India should fall behind in this exciting field. Also, India has a special situation obtaining with the spate of faint radio objects that will be discovered by GMRT; these will call for optical identification, and we must equip ourselves with a suitable large telescope for this purpose.

The Hubble Space Telescope, which will go into operation in 1990, will also discover many new faint objects especially in the vacuum ultraviolet. Detailed observations need to be made on these objects as well. The existing telescopes can only reach to objects that correspond to a third of the age of the universe. Larger telescopes will enable one to go to red shift of $z = 4$ or greater, which corresponds to epochs of galaxy formation. Studies on the abundance of Li, C, N, O and heavy elements in the distant objects reveal the early chemical history of the universe.

Transient phenomena are receiving increasing attention nowadays since they are characteristic of phenomena associated with gravitationally collapsed objects like white dwarfs, neutron stars and black holes, which accrete mass from companions. There are most challenging problems in astronomy to be tackled with large telescopes.

Two proposals were discussed:
(i) the UPSO 4-metre telescope
(ii) the giant optical telescope proposal of Indian Institute of Astrophysics (IIA).

3.2.4.1 *The UPSO proposal*

The proposal for the construction of a 4-metre optical telescope was made by the Uttar Pradesh State Observatory (UPSO) to the UP State Government during the Sixth Plan and was revived in the Seventh Plan. However, due to financial constraints the project did not materialize.

It is now proposed that this should be considered as a National Project to be funded during the Eighth Plan.

A detailed feasibility report on the structural aspects has been prepared by the Bhabha Atomic Research Centre (BARC). Site survey has also been done to a limited extent within the UP state boundary. Several promising sites in the Kumaon hills have been located.

It is proposed to import the 4-metre mirror blanks. The grinding and polishing of the blanks and the auxiliary optics are proposed to be done in-house at the State Observatory itself with consultancy being sought from IIA, the Central Scientific Instruments Organization (CSIO) and the Indian Institute of Tehnology (IIT), Delhi, and some foreign agencies. The control systems and the electronics will be carried out with the help of BARC.

3.2.4.2 *The IIA proposal*

IIA has proposed the construction of a 7-metre telescope as a national facility to be completed before 2000 AD. While detailed technical aspects have not been worked out, it is envisaged to incorporate the recent developments in the construction of large telescopes—thin mirrors, light-weight structures, adaptive optics, etc. Site survey has not been made.

3.2.5 Solar Vacuum Telescope

There are still very many fundamental processes peculiar to the solar atmosphere that need to be understood with higher and higher resolution telescopes. Recent observations from telescopes onboard spacecraft suggest that the magnetic fields on the solar surface are highly structured—in spatial extent as small as 200 km and strengths as high as 1 kilogauss—giving rise to very high magnetic pressure almost comparable to the gas pressure in the base of the photosphere. The relation between these and sunspots and the nonthermal heating of the solar atmosphere, chromospheric bright spots, need to be clarified. The relation between the dynamics of mass flows and solar activity, transient events giving rise to localized oscillations, micro- and nanoflares in the chromospheric are still a challenge. The Sun being our nearest star is undoubtedly the ideal laboratory for the study of a variety of stellar phenomena. High-resolution studies (1 arc sec) are feasible only with a vacuum telescope, in which the entire telescope and the spectrograph are evacuated to minimize the deterioration in seeing that takes place due to warm air and the heating of the optical components. A real breakthrough has come about in recent years that has enabled correction for seeing fluctuations in 'real time' through the use of active and adaptive mirrors.

There were three proposals in the area of solar astronomy:

(i) National Solar Vacuum Telescope, proposed by IIA

(primary mirror 60"–70", 0.2"–0.4" resolution)

(ii) Vacuum Optical Spar Telescope, by UPSO (45-cm aperture)

(iii) Helium-filled high-resolution National Solar Telescope, Spectrograph and Magnetograph, by Udaipur Observatory (36-cm aperture).

After discussion it became clear that the three proposals could be merged into one proposal for the construction of a large solar vacuum telescope.

3.2.6 One-metre class telescope facility

In recent years multiwavelength observations of celestial sources has become increasingly common to probe the nature of these sources and understand the radiation emission processes at work in them. This is one of the most active and fruitful areas of research in astronomy. With the advent of X-ray and gamma-ray astronomies and the special focus these have brought on transient phenomena and bursting sources it has become increasingly important to make either simultaneous observations or at least dedicated observations on specific sources. These kinds of observations do not come under the category of normal types of observations at optical wavelengths since the priorities of the optical astronomers are quite different. A noteworthy example of the power of multiwavelength observations is the one that has been made on the supernova SN 1987a in many laboratories at many different wavelengths. Similar is the need for observations on many of the X-ray and gamma-ray sources. Besides X-ray and gamma-ray astronomers, there is also a need expressed by infrared astronomers for having dedicated time available to make optical observations on some of the sources picked up in the far-infrared through observations by telescopes carried to balloon altitudes. Since adequate time is not available on existing telescopes there is a proposal by TIFR to import a 1-metre class telescope and install it in a good site exclusively for the dedicated observations of X-ray, gamma-ray and infrared sources.

3.2.7 Instrumentation centres

Every major discovery in astronomy is associated with the deployment of a new instrument or a new technique for the first time. Even not-so-major but significant advances are associated with the use of refined instruments of higher sensitivity and spatial and temporal resolutions. The advent of charge-coupled device (CCD) technology, which has introduced more than an order of magnitude sensitivity for existing optical telescopes, is a case in point. The newly developed image processing capabilities have provided radio astronomers structural resolutions of the most distant objects with a resolution unimagined earlier. Progress in infrared astronomy and space astronomies like X-ray and gamma-ray astronomies is a direct consequence of new-generation radiation detectors that were developed in different laboratories of the world and made suitable for operation in space environments.

While the major laboratories in India (IIA, RRI, TIFR, PRL, etc.) have in-house capability for developing and fabricating instruments, the smaller ones, particularly the ones in the universities, do not have this capability; this is one of the serious handicaps behind their inability to use national installations like VBT or ORT or the infrared telescopes. Even routine instrumentation that is required for teaching astronomy in colleges and universities is not readily available in the country. In the light of these requirements the proposal that is made by IUCAA for setting up an instrumentation centre is an excellent one.

The future of astronomical research in India, as in every other country, will depend on the ability to build larger and larger telescopes equipped with state-of-the-art focal-plane instrumentation. IIA, which built and commissioned the 2.34-metre Vainu Bappu Telescope, has acquired expertise and know-how in a variety of areas—mirror grinding/polishing, aluminizing, control and guidance systems, focal-plane instrumentation for a variety of uses, fibre-optic light-feed systems, cryogenic systems, etc.—

and also has trained personnel and laboratory and workshop equipment to play a major role in the fabrication and installation of large and medium-size telescopes that are required in the future, especially for the university departments and other research institutions.

3.2.8 Astronomical data centre

Astronomical research requires a number of large astronomical catalogues of objects that have been surveyed and studied in the different bands of the electromagnetic spectrum. Nowadays such information is most conveniently stored on magnetic tapes and disks. Special software packages are required to access the information stored in this manner. Clearly there is need for a centralised data base which can be reached through electronic mail by the various universities and research centres scattered all over the country.

Such catalogues are available from a number of sources, as also the software like IRAF, STARLINK, etc. It is necessary to have a work station like the advanced SUN, image processors, etc. at such a centre for data access, processing and distribution.

3.2.9. Development of special areas of astronomy and special techniques

3.2.9.1 TeV gamma-ray astronomy

The proposal of TIFR on TeV gamma-ray astronomy is for enhancing the capabilities of the existing system of 20 mirrors by the addition of 200 mirrors. The augmented system will be capable of operating at a lower threshold of 50 GeV and also will be in a position to check many claims based on episodal emissions from discreet gamma-ray sources, which, as of now, has not been confirmed or contradicted by independent groups. It is noted that this facility will not operate as a national facility in view of its special observational requirements. However it will be possible for individual scientists from institutions and universities to participate in the experiments.

3.2.9.2 Optical/IR aperture synthesis

The proposal of IIA on the optical/IR aperture synthesis is for carrying out feasibility studies in this area with the ultimate goal of realizing high-resolution spectroscopy of spatially resolved sources. From both scientific and technical points of view this is an emerging area of activity and needs a certain level of investment in the context of a long-term programme which needs to be defined with better clarity.

3.2.9.3 Segmented mirrors

The proposal of TIFR for exploring a cost-effective approach to develop segmented mirrors for use in large-aperture telescopes appears to be novel and interesting. If the procedure indicated in the proposal meets with success in the feasibility study phase it could be a potential cost-effective method of realizing mirrors for large telescopes. Further, keen interest was expressed by high energy astronomers interested in reflectors for collecting Cerenkov radiation from TeV gamma-ray showers. This activity is worth supporting as an initial investment towards developing technology for the large telescopes.

3.2.9.4 Instrumentation for pulsar research

The proposal for development of instrumentation for pulsar search and observations with GMRT is scientifically highly worthwhile and technologically feasible. This instrument, operated in conjunction with GMRT, is likely to result in the discovery of new millisecond and binary pulsars and would expand this field of study well beyond what has been achieved by the Arecibo telescope. In fact, with the steering capabilities of the GMRT, this will be the only facility in the world during the next four years to conduct research in regions of sky not covered by Arecibo. The critical area of development will be in respect of the parallel processor with a 1 gigaflop capability.

3.2.9.5 Gravity-wave detector

The proposal from IUCAA for conducting preparatory studies towards the realization of gravity-wave detectors has objectives which are fundamental both from astrophysics and physics standpoints. The experimental system calls for some of the most demanding technologies and techniques which are not realized even abroad. Among the critical technologies needed, the most important ones are laser optics with high-stability lasers, vacuum techniques to realize 10^{-8} torr in large volumes and techniques of seismic isolations of testmass. The technological feasibility at present is not adequately proven and has to be established through a feasibility project which could be examined separately by DST. Suitable technical manpower development is most crucial for this project.

3.2.9.6 The French Schmidt Telescope

The CERGA Schmidt Telescope is a 90/150 cm telescope presently operational in the south-east of France at a height of 1270 metres. During the High-Energy Astronomy Meeting held in Delhi as part of the Indo-French Festival, an offer was made by the French scientists to bring this telescope to India and set it up in a suitable high altitude site (3000 m) for observations in the ultraviolet for which the telescope is specially suitable, since it has a fused-quartz corrector. It has a plate scale equivalent to that of the Palomar Schmidt and has 5.5° x 5.5° field. The telescope can be used for galactic, extragalactic and solar system astronomy.

UPSO scientists are very much interested in this offer. Dr Vijay Mohan of UPSO has worked with this telescope as part of his PhD work in France. A suitable site at Devastal, 20 km from Nainital, has been located. However, the height is lower than what the French have stipulated. The full and efficient utilization of this telescope depends on the import of special ultraviolet sensitive photographic plates and an electronic data analysis machine of the type Mama made in France, or its American equivalent.

3.2.10 Upgradation of existing facilities

In the area of optical astronomy there are three major work horses in the country that have been contributing to most of the astronomical research in the last few decades. They are (i) the Japal Rangapur 48-inch Telescope operated by Osmania University and used by several institutions, (ii) the 104-cm UPSO Telescope at Nainital, and (iii) the 102-cm IIA Telescope at Kavalur. All these need upgradation and modernization and detailed proposals are available in the plan proposals submitted by the respective institutions. Of these Japal Rangapur Telescope needs extensive repair and adjustments.

The major additions that have been requested by the various institutions are (i) CCD cameras, (ii) VAX or Micro-VAX computers, (iii) special filters and (iv) spectrographs, all of which are essential to make these facilities up-to-date and suitable for studies in frontier areas of astronomy.

In the area of solar astronomy, there are a complex of several telescopes, at Kodaikanal, at Nainital and at Udaipur. All these also need upgradation.

Improvements and augmentation of ORT have also been proposed, essentially from the point of view of making the telescope a very effective VLBI instrument. For this purpose MK II VLBI processors will be added. A new Pulsar Receiver Project has been proposed which enhances the capabilities of ORT for pulsar searches, study of the effects of interstellar medium, and single-pulse studies.

3.2.11 The Positional Astronomy Centre

The proposal from the Positional Astronomy Centre (PAC), Calcutta, has three major components. The first envisages strengthening and improving the existing service capabilities of the centre (involving making available ephemeris information and such other related data); the second is related to establishment of a group in celestial mechanics and dynamical astronomy to improve accuracy of the ephemeris calculations; the third concerns deriving hands-down experience for the staff of the centre by carrying out observational studies in positional astronomy and astrometry. There is a clear case for strengthening PAC in respect of bringing out new publications and modernizing data services as well as stabilizing the capabilities for improving ephemeris calculations through the creation of competent groups in the areas of celestial mechanics and dynamical astronomy. Further, the existing activities in the area of history of astronomy and calendars should also be supported. However, it will be more appropriate for this centre to get the hands-down experience for its staff by attaching them periodically to some of the well-known astronomical institutions in the country. Such a step would enable its staff to get broadbased exposure to related techniques in an environment of better infrastructure and other facilities.

4 RECOMMENDATIONS

The recommendations which follow are based on intensive discussions held during the meeting in Bangalore where separate working groups as well as independent peer groups looked at the various proposals in fair amount of detail. At the meeting the astronomy community of 60–65 scientists, representing a broad cross-section of institutions as well as disciplines, had the opportunity to discuss the various national programmes in the area of astronomy and to express themselves clearly and individually on the proposals. The priorities which have been arrived at do reflect, to a great extent, the overall views of the astronomy community. It is hoped that these recommendations would be used by the Planning Commission for allocating resources during the Eighth Five-Year Plan.

4.1 MANPOWER DEVELOPMENT, **Recommendation 1**

From the point of view of full utilization of the various facilities that have been created, and are proposed to be created, and also for the nation to participate and forge ahead at the highest creative levels in the expanding fields of astronomy and astrophysics, it is most important that highest priority is placed in the Eighth Plan period on the creation of *young scientific manpower*—astronomers, physicists, chemists and engineers who are trained in the different fields of astronomical research after they go through suitably designed courses as part of their university education. To achieve this it is necessary to create regional and national centres within the university system; to begin with, simple optical and radio telescopes should be provided at selected universities for training purposes. *For this purpose an allocation of Rs 10 crores has been proposed in the Eighth Five-Year Plan* (this includes resources for the Rangapur Telescope at Osmania University). This allocation should be made to UGC in such a way that specific budgets are given to universities directly for utilization in astronomy programmes. The detailed proposal for this would have to be processed by UGC\DST.

4.2 NATIONAL FACILITIES, **Recommendation 2**

Recognizing that major facilities would be available in the Eighth Plan in different institutions, it is felt necessary that the Planning Commission/DST, in consultation with the host institution, decide which of the facilities available in the Eighth Plan could be considered as 'National Facilities'. If the host institution agrees to designating such facilities as National Facilities, additional funds could be provided for research training programme, visits of research scientists, fellowship programmes for students, as well as funds for some small R&D projects which would involve making observations at the national facility. These activities would have to be processed and monitored under an independent committee consisting of members of the astronomy community mainly from outside the host institution. It is recommended that the Planning Commission, while allocating resources for the Eighth Plan, clearly designate selected facilities as National Facilities on the above lines. A sum of Rs. 3 crores is recommended for this purpose in the Eighth Plan.

4.3 EXISTING FACILITIES

It was recognized that investments already made in the existing national facilities (optical telescopes, radio telescopes, laboratory facilities, etc.) during the Seventh Plan must be fully made use of as truly national facilities by ensuring that these projects are completed during the Eighth Plan and all infrastructure, including travel, fellowships, training programmes, etc., are organized at these national facilities for young astronomers and other research users. It will be necessary to set up appropriate national committees to ensure that the facilities are operated with the above objectives in mind. Specific recommendations for the existing facilities are given below.

4.3.1 Recommendation 3a, The Giant Metre-wave Radio Telescope Project (GMRT)

The GMRT project, on which investments to the tune of Rs. 10 crores have already been made in the Seventh Plan, should be completed during the Eighth Plan period. It should be ensured that there is no spillover of this project in terms of major investments to the Ninth Plan. The GMRT project, which received the highest priority at this national meeting, should be given the required funds of Rs. 30 crores to ensure that it becomes fully equipped and fully operational to pursue research at the international level of competition in the exciting scientific objectives outlined for this project.

4.3.2 Recommendation 3b, Vainu Bappu Telescope (VBT)

VBT, which has made considerable progress during the last years of the Seventh Plan, should be completed during the Eighth Plan period, and resources to the tune of Rs. 5 crores should be allocated for this project where the necessary infrastructure in terms of front-end instruments and other facilities should be made available at this national facility. All aspects connected with its maintenance and smooth running of the various subsystems have to be ensured. The astronomy community in the country desirous of getting observation time on this facility should be well informed about the mechanisms through which observation time would be available to scientists. A 'peer review' system for examining the various proposals received must be set up and made widely known. While some time would have to be reserved for the host institution, a national committee should ensure that a wide cross-section of the community and research students are able to make use of this facility.

4.3.3 Recommendation 3c, The 48-inch Rangapur Optical Telescope

It was noted that the Rangapur 48-inch telescope could be still made operational through the total overhauling of the systems as proposed by SHAR engineers. It is recommended that this be speedily undertaken, if necessary through international expertise as well, and the system be made fully operational. The organizational aspects of making the Rangapur Telescope operate as a national facility should be speedily worked out between UGC and Osmania University. The resources required for this have been projected in the manpower development programme in the universities and should be utilized only after it is ensured that it operates as a national facility.

4.3.4 Recommendation 3d, The one-metre class optical and IR telescopes

The one-metre class optical telescopes at Nainital and Kavalur and the Gurushikhar IR Telescope of PRL should be provided funds through the normal institutional budgets consistent with their activities under the Seventh Plan for upgrading and modernizing as well as completing the telescope systems. It is expected that mostly operational budgets are required for these facilities now. In case these telescopes are proposed to be used as national facilities separate funds could be given for running specific programmes as approved by the national committee set up for each facility.

4.3.5 Recommendation 3e, Existing radio telescopes

The Ooty Radio Telescope, the 10-metre millimetre-wave radio telescope, PRL Radio Array and the Gauribidanur Array should be provided with appropriate funds through their normal institutional budgets, consistent with their activities in the Seventh Plan. It is expected that only operational budgets are required for these facilities now. In case some of these telescopes are proposed to be used as national facilities, separate funds should be given to these facilities for running specific programmes as approved by the national committee set up for each facility.

4.4 NEW FACILITIES

In addition to the existing facilities there is a need for setting up new facilities. These were clearly identified with certain prioritization during the Bangalore meeting. The recommendation for these are as follows.

Recommendation 4, National Large Optical Telescope $\geq$4 m.)

Proposals for large optical telescopes were received from UPSO, Nainital; and IIA, Bangalore. It was recommended that these should be looked at in an integrated manner. There is a clear need for setting up a most modern large-sized optical telescope in the best possible site in the country well before the end of this century. Investments and initiatives have to be therefore taken during the Eighth Plan so that this telescope is realized by the end of the Ninth Plan. While planning for a large optical telescope in the '90s, it is important that all the options, including new-technology telescopes built around thin mirrors and incorporating active and adaptive optics, multi-mirror technologies, etc., are carefully examined and decisions arrived at by technically competent committees in as short a time as possible. The first priority should be the identification of an *ideal site* and an optimal design for the telescope. A task force should be set up to take the necessary action in these matters. Foreign experts should be identified and invited for consultations as necessary. Three technical workshops to discuss and finalize various aspects of this proposal have been recommended to be organized by IIA during the period October to December 1989 (DST has already approved in principle these three workshops to be funded by them). *It is estimated that for the large optical telescope programme a provision of Rs. 5 crores should be made during the Eighth Five-Year Plan.* Provision of Rs. 50 crores would have to be reserved in the Ninth Plan for completion of this project.

4.5 SOLAR ASTRONOMY

Proposals from IIA, Bangalore; UPSO, Nainital; and USO, Udaipur, were examined. It was proposed that there should be an integrated national programme for solar astronomy and major efforts should be made in an integrated manner.

Recommendation 5, National Solar Vacuum Telescope
Considering the remarkable developments that are taking place in the field of solar astronomy and considering the Indian interest and contribution in this field, the country should also plan to have a solar telescope of the most up-to-date design before 2000 AD. In the execution of this programme considerations of site selection and design feasibilities would have to be given topmost priority during the Eighth Five-year Plan. *For this purpose it is recommended that a sum of Rs. 5 crores be made available for the National Solar Vacuum Telescope (NSVT) programme.* A provision of Rs. 10 crores would have to be reserved in the Ninth Plan for this activity.

4.6 INSTRUMENTATION FACILITIES

It was recognized that, in the field of experimental astronomy, if a large number of astronomers have to make use of various national facilities to be operational during the Eighth Plan and beyond, there is a clear need to focus national attention on the problems connected with development of instruments required for using the various facilities. For this purpose there were two proposals for enhancing the astronomy instrumentation programmes in the country. Recommendations on these two proposals are as follows.

4.6.1 Recommendation 6a, IUCAA Instrumentation Centre

It is necessary that a separate instrumentation centre is set up which will primarily concentrate on the design and fabrication of instruments that are specifically required for imparting training and for evolving some research programmes in astronomy in universities and colleges. *The IUCAA proposal which envisages such an activity could be supported to the tune of Rs. 50 lakhs during the Eighth Five-Year Plan period.* However, it is necessary that the IUCAA group is strengthened with scientists having experimental physics and instrumentation background and also with active participation and association with the GMRT group also located in Pune.

4.6.2 Recommendation 6b, Instrumentation Centre at IIA

Taking cognisance of the fact that considerable expertise has been built up over the years by IIA in connection with the Vainu Bappu Telescope, in the fields of mirror grinding, optics, control system for telescope, dome design, installation of telescopes, etc., it is recommended that a National Astronomical Instrumentation Centre be set up at IIA, drawing the necessary personnel from other institutions as well. Such a centre could also be entrusted (if so decided by UGC) with the design and fabrication of the 14-inch class telescopes that are recommended for installation in several universities in connection with the manpower training programme. The question whether such a centre would be able to fabricate and install the requirements of so many 14-inch class telescopes in the university system within a short time was not, however, clear and the option of importing the 14-inch class telescopes for the universities has been kept open. The instrumentation centre could however take up the responsibility of ensuring that these telescopes (imported or indigenously developed) are installed and made operational at various universities. This itself is considered as a major task to which the instrumentation centre would have to give very high priority.

4.6.3 Recommendation 6c, The Saha Observatory

The IIA Instrumentation Centre should have the capacity for designing and fabricating 1–1.5-metre telescopes of the type that has been proposed to be imported by some research groups. At least one such telescope should be built before 1994 and installed in a good site for use by research groups like TIFR, the Nuclear Research Centre, Srinagar, and universities on a time-sharing basis. The year 1993 being the Megnad Saha Centenary Year, it would be appropriate if such an observatory is named the Saha Observatory. *For this activity of the National Instrumentation Centre at IIA, it is proposed that Rs. 1 crore be given for setting up the necessary infrastructure. Additional resources to the tune of Rs. 6 crores would have to be made available if the centre also takes the responsibility of fabricating the 1–1.5-metre telescope for the Saha Observatory.* The funds for the 14-inch class telescope, provided in the university programme, would also have to be made available to the IIA Centre if it is given the responsibility of fabricating the 14-inch class telescope.

4.6.4 Recommendation 6d, Technical developments for large mirrors

Individual scientists and institutions should be encouraged in their efforts to design and test new ideas that have a bearing on the construction of future large telescopes. *A proposal received from TIFR in this connection was recommended for support with an investment of about Rs. 30 lakhs in the Eighth Plan period.*

4.7 ASTRONOMY DATA CENTRE, **Recommendation 7**

There is a need for setting up a modernized astronomy data base that could serve the need of all the astronomy centres in the country, including the new centres in the university sectors, which could all be linked by electronic mail. Such a centre, which could be part of the IUCAA activities, could be set up at Pune. The emphasis in the initial stages should be on building a sound astronomical catalogue data base first and not the archival data collection which was also proposed. This activity of archival data collection could be taken up later if necessary. *During the Eighth Five-Year Plan, for this activity of astronomy data base, an amount of Rs. 50 lakhs could be made available to IUCAA.*

4.8 SCHMIDT TELESCOPE, **Recommendation 8**

The proposal of the French Government to move their Cerga Schmidt Telescope to a suitable site in India for use by both Indian and French astronomers should be explored further. Though at the present moment the number of users seems to be small, there is a possibility that, through the activities of IUCAA, there could be many more potential users, and to that extent the priority of this project is low and its future growth will be determined by the actual users who come forward with specific proposals. Recognizing that this is a modern telescope of high quality that can be used specially for ultraviolet survey of the sky, the Government is requested to pursue the offer of the French Government. For this, a suitable site which is acceptable to the French astronomers would have to be identified and also negotiations with the French Government undertaken for obtaining data analysis equipment and other accessories which could otherwise be very expensive. *It is proposed that, if through these negotiations, India is able to get favourable support from the French Government (including support on the instrumentation facilities), an investment to the tune of Rs. 3 crores may have to be made during the Eighth Five-Year Plan.*

4.9 POSITIONAL ASTRONOMY CENTRE, **Recommendation 9**

The Positional Astronomy Centre, which caters to the needs of a variety of agencies by providing the Indian Astronomical Ephemeris and calendric information, needs to be strengthened and modernized. The upgradation proposal should be examined by the India Meteorological Department/DST under which the centre operates. The requirement of resources which they have projected for the Eighth Five-Year Plan would have to be given support.

4.10 GENERAL RECOMMENDATIONS

It was recognized that some of the programmes of institutions like RRI, TIFR, PRL, IIA, etc. were run as part of the institutional programmes and were not projected as national facilities. It is expected that requirements of these institutions would be mostly operational requirements and would not involve major new allocations. The institutional proposal of TIFR for upgrading the Pachmarhi UHE Gamma Ray Array at a cost of Rs. 3 crores did receive high priority at the meeting.

During the meeting, members of the astronomy community had a very good opportunity to interact with each other and, at the same time, of becoming familiar with the various major programmes in astronomy being carried out in the country. Such a forum provided in-depth information as well as constructive criticism about the capabilities and potential of our astronomy community as a whole. There were suggestions that the Planning Commission/DST may set up a Standing Committee to overview the astronomy programmes in the Eighth Plan, on an annual or biennial basis, so as to provide continuous feedback for development of astronomy programmes during the coming decade.

It is estimated from the figures given by the Planning Commission that an amount of approximately Rs 43 crores was devoted for astronomy activities in the various institutions during the Seventh Plan. During the Eighth Plan the allocation for astronomy activities as a whole, inclusive of institutional requirements, may reach the tune of about Rs. 90–100 crores, of which about *Rs. 70 crores* would be allocation for new projects in terms of *National Facilities.* A summary of the financial outlay proposed for the various programmes to be undertaken during the Eighth Five-Year Plan are given in the next section. These are given in the order of priority, though it must be recognized that, based on the readiness of individual proposals, the relative allocation of resources may have to be shifted as time progresses.

4.11 RECOMMENDED OUTLAY FOR ASTRONOMY PROGRAMMES DURING THE EIGHTH FIVE-YEAR PLAN (1990–95) – SUMMARY

			Rs. in crores	
			Existing	New
1.	(i)	Manpower development in universities (including telescope costs, installation for optical, radio telescopes and upgradation of Rangapur Telescope)		10
	(ii)	National research and training programmes		3.5
2.	(i)	Giant Metre-wave Radio Telescope (GMRT) (completion)	30	
	(ii)	10-metre Millimetre-wave radio telescope	Institutional	
	(iii)	Gauribidanur Array	Institutional	
	(iv)	Ooty Radio Telescope (Rs. 1.00 crore)	Institutional	
	(v)	Pulsar Machine for GMRT		Institutional
3.		*Optical and IR Astronomy*		
	(i)	Vainu Bappu Telescope (VBT) (completion)	5	
	(ii)	Large Optical Telescope (preparatory work)		5
	(iii)	1–1.5-metre telescope (fabrication)		6
	(iv)	UPSO Telescope (modernization)	Institutional (State)	
	(v)	Gurushikhar IR (completion)	Institutional	
	(vi)	Schmidt Telescope (Indo-French collaboration; installation, accessories)		3
	(vii)	Large mirror fabrication techniques (development)		0.30
4.		Solar astronomy		
	(i)	National Vacuum Telescope (preparatory work)		5
	(ii)	Udaipur Solar Observatory (limited upgradation)	Institutional	
	(iii)	UPSO Solar Observatory	Institutional	
5.		Ultra-high-energy gamma astronomy (Rs. 3.00 crores)	Institutional	
6.		Instrumentation centres		
	(i)	IIA		1.0
	(ii)	IUCAA		0.5
7.		Astronomical data centre		
	(i)	IUCAA Catalogue Data Centre		0.5
8.		Positional Astronomy Centre (Modernization, upgradation)		Met. Dept
		Total (National Facilities, excluding institutional funds for continuing programmes and upgradation)	35.00	34.89
		say, Rs	70.00 crores	
Note:		Regular institutional budget requirements are estimated to be of the order of about Rs. 30.00 crores	30.00 crores	
		Grand	100.00 crores.	

5. ANNEXURE: LIST OF PARTICIPANTS

I. SPECIAL INVITEES

1. Prof. B.V. Sreekantan (Chairman)
Tata Institute of Fundamental Research,
Homi Bhabha Road, Colaba,
Bombay 400 005

2. Prof. R.R. Daniel,
Secretary, COSTED,
Asia Regional Office,
24, Gandhi Mandap Road,
Guindy,
Madras 600 025

3. Prof. S. Ramaseshan,
Raman Research Institute,
Sadashivanagar P.O.,
Bangalore 560 080

4. Dr. K. Kasturirangan,
ISRO Satellite Centre,
Airport Road, Vimanapura P.O.,
Bangalore 560 017

II. UNIVERSITIES AND IUCAA

(a) Universities

5. Prof. N.C. Mathur,
Vice-Chancellor,
Roorkee University,
Roorkee 247 667

6. Prof. K.D. Abhyankar,
Department of Astronomy,
Osmania University,
Hyderabad 500 007

7. Prof. M.B.K. Sarma,
Director, CASA,
Osmania University,
Hyderabad 500 007

8. Dr. Gopalachary Kilamby,
Department of Astronomy,
Osmania University,
Hyderabad 500 007

9. Dr. D. Banhatti,
Physics Department,
Madurai Kamaraj University,
Madurai 625 021

10. Prof. H.S. Gurm,
Department of Physics and Astronomy,
Punjab University,
Patiala 147 002

11. Prof. Sriranjan Banerji,
Department of Physics,
The University of Burdwan,
Burdwan 713 104

12. Dr. Sapre,
Department of Physics,
Ravi Shankar University,
Raipur 492 002

13. Prof. J.N. Tandon,
Department of Physics and Astrophysics,
Delhi University
Delhi 110 007

14. Dr. A.K. Sen,
Institute of Radio Physics and Electronics,
Calcutta University,
92 Acharya Prafulla Chandra Road,
Calcutta 700 009

15. Prof. S. Ramadurai,
Astronomy Programme, Dept. of Physics,
Indian Institute of Science,
Bangalore 560 012

(b) IUCAA

16. Prof. J.V. Narlikar,
Inter University Centre for
Astronomy and Astrophysics (IUCAA),
Poona University Campus,
Pune 411 007

17. Prof. N.K. Dadhich,
Inter University Centre for
Astronomy and Astrophysics (IUCAA),
Poona University Campus,
Pune 411 007

18. Dr. A.K. Kembhavi,
Inter University Centre for
Astronomy and Astrophysics (IUCAA),
Poona University Campus,
Pune 411 007

19. Dr. S.V. Dhurandhar,
Inter University Centre for
Astronomy and Astrophysics (IUCAA),
Poona University Campus,
Pune 411 007

III. NATIONAL LABORATORIES/INSTITUTES

(a) Indian Institute of Astrophysics, Bangalore.

20. Prof. J.C. Bhattacharyya,
Director,
Indian Institute of Astrophysics,
Sarjapur Road,
Bangalore 560 034

21. Dr. N.K. Rao,
Indian Institute of Astrophysics,
Sarjapur Road,
Bangalore 560 034

22. Dr. Ashok Patil,
Indian Institute of Astrophysics,
Sarjapur Road,
Bangalore 560 034

23. Prof. K.R. Sivaraman,
Indian Institute of Astrophysics,
Sarjapur Road,
Bangalore 560 034

24. Dr. S.P. Bagare,
Indian Institute of Astrophysics,
Sarjapur Road,
Bangalore 560 034

25. Dr. Ch. V. Sastry,
Indian Institute of Astrophysics,
Sarjapur Road,
Bangalore 560 034

26. Dr. P. Venkataraman,
Indian Institute of Astrophysics,
Sarjapur Road,
Bangalore 560 034

27. Dr. A.K. Saxena,
Indian Institute of Astrophysics,
Sarjapur Road,
Bangalore 560 034

28. Dr. M. Parthasarthy,
Indian Institute of Astrophysics,
Sarjapur Road,
Bangalore 560 034

29. Prof. N.A. Narasimhan,
Indian Institute of Astrophysics Council Member,
Indian Insitute of Astrophysics,
Sarjapur Road,
Bangalore 560 034

(b) *Radio Astronomy Centre (RAC), Ooty/Bangalore.*

30. Prof. G. Swarup,
TIFR Centre,
Post Box 1234,
Indian Institute of Science Campus,
Bangalore 560 012.

31. Dr. S. Ananthakrishnan,
GMRT Centre,
Poona University Campus,
Ganeshkhind,
Pune 411 007.

32. Dr. T. Veluswamy,
Radio Astronomy Centre (TIFR),
P.O. Box 8,
Udhagamandalam (Ooty) 643 001

33. Shri S.C. Tapde,
TIFR Centre,
Post Box 1234,
Indian Institute of Science Campus,
Bangalore 560 012

34. Dr. D.J. Saikia,
GMRT Centre,
Poona University Campus,
Pune 411 007

35. Dr. Ravi Subrahmanya,
Radio Astronomy Centre (TIFR),
P.O. Box 8
Udhagamandalam (Ooty) 643 001

36. Dr. V.R. Venugopal,
Radio Astronomy Centre (TIFR),
P.O. Box 8,
Udhagamandalam (Ooty) 643 001

(c) *Tata Institute of Fundamental Research, Bombay.*

37. Prof. P.C. Agrawal,
Space Physics Group,
Tata Institute of Fundamental Research,
Homi Bhabha Road, Colaba,
Bombay 400 005

38. Prof. S.N. Tandon,
Space Physics Group,
Tata Institute of Fundamental Research,
Homi Bhabha Road, Colaba,
Bombay 400 005

39. Prof. P.V. Ramanamurthy,
Tata Institute of Fundamental Research,
Homi Bhabha Road, Colaba,
Bombay 400 005

40. Dr. P.N. Bhatt,
Tata Institute of Fundamental Research,
Homi Bhabha Road, Colaba,
Bombay 400 005

41. Dr. K.P. Singh
Tata Institute of Fundamental Research,
Homi Bhabha Road, Colaba,
Bombay 400 005

(d) *Raman Research Institute, Bangalore*

42. Prof. N.V.G. Sarma,
Raman Research Institute,
Sadashivanagar P.O.,
Bangalore 560 080

43. Dr. Vivek Dhawan,
Raman Research Institute,

Sadashivanagar P.O.,
Bangalore 560 080

44. Dr. A.A. Deshpande,
Raman Research Institute,
Sadashivanagar P.O.,
Bangalore 560 080

45. Prof. G. Srinivasan,
Raman Research Institute,
Sadashivanagar P.O.,
Bangalore 560 080

46. Dr. R. Nityanand,
Raman Research Institute,
Sadashivanagar P.O.,
Bangalore 560 080

47. Dr. N. Udaishankar,
Raman Research Institute,
Sadashivanagar P.O.,
Bangalore 560 080

(e) Physical Research Laboratory, Ahmedabad.

48. Prof. P.V. Kulkarni,
Physical Research Laboratory,
Navarangpura,
Ahmedabad 380 009

49. Dr. Arvind Bhatnagar,
Udaipur Solar Observatory,
11, Vidya Marg,
Udaipur 313 001

(f) Other Laboratories

50. Mr. A.K. Bhatnagar,
Director,
Position Astronomical Centre,
P-546-Block N,
New Alipore,
Calcutta 700 053

51. Dr. C.L. Bhat,
Bhabha Atomic Research Centre,
Nuclear Research Laboratory,
Zakura,
Srinagar 190 006

IV. STATE LABORATORIES

52. Dr. M.C. Pande,
U.P. State Observatory,
Manora Peak,
Nainital 263 129

53. Dr. H.S. Mahra,
U.P. State Observatory,
Manora Peak,
Nainital 263 129

54. Dr. Vijay Mohan,
U.P. State Observatory,
Manora Peak,
Nainital 263 129

55. Dr. S.K. Gupta,
Project Scientist,
U.P. State Observatory,
Manora Peak,
Nainital 263 129

56. Dr. V.P. Gaur,
U.P. State Observatory,
Manora Peak,
Nainital 263 129

V. AGENCY REPRESENTATIVES

57. Dr. S. Ramanathan,
Joint Adviser (S & T),
Planning Commission,
Yojana Bhavan,
New Delhi 110 001

58. Dr. M.D. Tiwari,
University Grants Commission,
Bahadurshah Zafar Marg,
New Delhi 110 002

59. Dr. T.M.K. Marar,
ISRO Satellite Centre,
Airport Road, Vimanapura P.O.,
Bangalore 560 017

60. Dr. M.K. Tiwari,
ISRO Satellite Centre,
Airport Road, Vimanapura P.O.,
Bangalore 560 017

61. Dr. S.R. Gowariker,
Director, CSIO,
Sector - 30
Chandigarh 160 020

62. Dr. Govindarajan,
Bhabha Atomic Research Centre,
Bombay 400 085

63. Dr. G.S.K. Murthy,
Bhabha Atomic Research Centre,
Bombay 400 085

64. Dr. J.K. Sharma,
Department of Science and Technology,
Technology Bhavan,
New Delhi 110 016

65. Dr. P.J. Lavakare (Convener),
Adviser,
Department of Science and Technology,
Technology Bhavan,
New Mehrauli Road,
New Delhi 110 016